Meteorological Tower Placement Report to the
Virginia Offshore Wind Development Authority (VOWDA)

Virginia Department of Mines, Minerals, and Energy

Updated Report – 03 October 2011 – Review Draft

The Virginia General Assembly, in 2010, established the Virginia Offshore Wind Development Authority (VOWDA) to facilitate the development, either by the Authority or by other qualified entities, of the offshore wind energy industry, offshore wind energy projects, and associated supply chain vendors. One specific duty that VOWDA may undertake is collecting relevant meteorological and oceanographic (metocean) and environmental data. The enabling legislation requires DMME to prepare a report on "the appropriate placement of meteorological towers and necessary renovations to existing structures" (Reference 1). This report fulfills that requirement.

- Section 1 of this report describes the types of metocean data needed to inform and accelerate offshore wind project development off Virginia.

- Section 2 catalogues the various metocean data sources that are now available on Virginia's outer continental shelf (OCS).

- Section 3 describes the state-of-the-art in offshore wind resource assessment to achieve a "bankable" project and recent results from Denmark that suggest how calibrated and traceable ground-based vertical-profiling LIDAR (LIght Detection And Ranging) can reduce uncertainty in estimating annual energy production, thereby improving project financing terms.

- Section 4 describes the existing uses and present status of the Chesapeake Light Tower (CLT), and summarizes the opportunities and challenges posed by refurbishing it as a metocean and environmental data collection platform. The CLT is the only "existing structure" on Virginia's OCS to which the VOWDA enabling legislation applies

- Section 5 recommends a phased development approach whereby outfitting the CLT with appropriate instrumentation will enable Virginia to begin characterizing its offshore wind resource at a fraction of the cost of a new met tower in the initial phases of this work. This will enable data analysis and resource characterization in a public process subject to peer review, with wider dissemination of results more quickly than if such metocean measurements were left entirely to commercial project developers and thus will encourage more rapid growth of Virginia's offshore wind industry. Moreover, the recommended instrumentation will be key assets for advanced offshore turbine testing, which could be a foundational enterprise to grow and attract offshore wind businesses and more quickly create new jobs and capabilities in Virginia's offshore wind supply chain.

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Section 1. Metocean Data Needs for Offshore Wind Turbine Selection and for Project Financing, Design, Construction, and Operation

<u>Urgent Need for Offshore Wind Data to Inform Turbine Design</u>

Wind developers and government agencies need metocean data to design, construct, and operate offshore energy projects and for the attendant federal regulatory process. According to an analysis by the Virginia Coastal Energy Research Consortium (VCERC; Reference 2), the federal process for an offshore wind project developer to obtain a non-competitive lease is estimated to take between 10 and 21 months, while the competitive lease process could require 21 to 36 months. Thus, commercial wind projects in federal waters on Virginia's OCS might need 1-2 years to obtain a non-competitive lease, or 2-3 years to obtain a lease if a competitive lease auction is required. These timelines may be somewhat shortened by recent changes to the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) leasing process under its "Smart from the Start" initiative announced in Norfolk on 07 February 2011.

Assuming that BOEMRE issues its Virginia Call for Information and Nominations (Call) in October 2011, a developer could expect to be awarded a lease by year-end 2012 in the case of a non-competitive lease, and perhaps a year or two later if a competitive lease auction must be held to resolve competing nominations. Based on European experience with projects in the size range of 200 MW to 500 MW, VCERC estimates that 3 to 5 years will be needed to complete the following lease development activities: acquisition of metocean and geological & geophysical data for project design, acquisition of baseline environmental data for permitting, securing a grid interconnection agreement, and negotiating a power purchase agreement.

Under the most optimistic commercial development scenario (a 1-year non-competitive leasing phase and 3-year project development phase), the earliest when a project developer could be ready to close its project financing and order long-lead items such as wind turbines, submarine power cables, and installation vessel charters, would be year-end 2016. Under the most pessimistic scenario (a 3-year competitive leasing phase and 5-year project development phase), long-lead orders would not be placed until year-end 2020. The most likely scenario would be midway between these two, with long-lead orders placed at year-end 2018.

As detailed in Reference 2, having turbines supplied from an assembly plant in Hampton Roads rather than from Europe could reduce the cost of an offshore wind project by nearly $500 per installed kilowatt and lower the cost of energy by 1.5 cents per kWh. In order for serial production from a new plant to begin at year-end 2016 for turbine delivery by year-end 2018 (most optimistic scenario), a turbine manufacturer's decision to invest in such a plant and qualify its supply chain should be made by year-end 2015.

This implies that key turbine design parameters, such as rotor swept area per unit generator capacity and tower-top mass per unit generator capacity, should be known by year-end 2015 to meet the most optimistic commercial development schedule. Thus a major goal of the offshore wind mapping program recommended in this report would be to have measured at least one year of design-usable data by mid-2015, suggesting that *wind-profiling LIDAR buoys or new-build volume-scanning LIDAR platforms for mapping Virginia's commercial lease area be installed and **begin measurements by the summer of 2014**.*

<u>Metocean Data Needed for Project Financing, Design, Construction, and Operation</u>

It is commonly thought that to obtain offshore wind project financing, a meteorological tower must be erected within the project footprint, to measure wind speed and direction at multiple elevations above sea level, up to a "best practice" elevation of at least 2/3 of turbine hub height for at least one year in order for such data to be "bankable" (Reference 3).

One U.S. merchant project developer (Reference 4) estimates the cost of such a dedicated tower to be $4 - $7 million, depending on location, type of foundation and the instrumentation that is included. Another U.S. merchant developer (Reference 5) has documented offshore met tower costs ranging from $2.5 million for the Cape Wind project (5-m water depth, 60-m height, with three anemometer elevations) to over $10 million for the FINO-1 platform offshore Denmark (30-m water depth, 100-m height, with eight anemometer elevations, helicopter access).

Because obtaining such project-specific measurements is so costly, an increasing number of European offshore wind farms are being financed based on revenue projections derived from numerically modeled weather data, which have been validated by physical measurements near, but not within, the project site (Reference 6). In responding to DMME's questionnaire soliciting stakeholder input for this report, Virginia's incumbent electric utility has stated (Reference 7):

> At this point in time, upgrading the CLT [Chesapeake Light Tower] should be
> a priority, not to provide financing in preparation for a specific project, but to
> provide more detailed information on the wind resource in order to prepare
> Virginia for the offshore wind industry… Using the CLT to validate less costly
> measurement devices in lieu of project-specific met towers provides useful data
> for scientific evaluation, policy development, and initial project development.

Recent presentations by representatives from banks that have financed European offshore wind projects have suggested that a much bigger revenue risk than uncertainties in the hub height wind resource, *per se*, is the risk of lost revenues due to turbine inaccessibility for service visits caused by poor weather (References 8, 9 and 10). This is particularly true considering that inaccessibility is more likely to occur during high-wind periods when the output (and earned revenue) of a properly functioning turbine would be greatest. The five key metocean parameters governing offshore wind access are:

- Wind speed;
- Wave height;
- Wave period;
- Surface current speed; and
- Visibility.

Optimizing offshore maintenance strategies requires *a priori* knowledge of the above conditions in order to design a project for least risk of revenue loss (Reference 11).

Metocean conditions also affect the design (e.g. appropriate floating equipment selection), scheduling, and safe conduct of offshore construction activities: staging, transport and installation of foundations, towers, turbines, and submarine power cables. Indeed, representatives from banks who finance offshore wind projects suggest that one of the best ways to mitigate against offshore wind project construction delays and cost-overruns is to develop

accurate metocean forecasting capabilities (References 8 and 9). The same five metocean parameters that govern offshore access for maintenance also govern the design, scheduling and safe conduct of offshore construction activities (Reference 11).

Finally, reliable days-ahead forecasting of offshore wind conditions would improve the ability of projects to operate cost-effectively in the PJM regional transmission market. In particular, accurate wind speed forecasts reduce fees for load balancing and other ancillary services that PJM would charge against interconnected offshore projects.

Based on the above considerations, this report recommends a metocean data collection and environmental monitoring program that will attract lower-cost financing terms for offshore wind projects on Virginia's continental shelf. This is based on evaluation of existing metocean data sources (next section), the availability of the Chesapeake Light Tower as an existing platform of opportunity (third section), and the long timetable before project developers will be able to measure site-specific data on their commercial leases.

Section 2. Existing Metocean Data Sources on Virginia's Outer Continental Shelf

There are three basic types of metocean data sources publicly available to offshore wind turbine manufacturers, commercial project developers, and federal regulatory and permitting agencies: measurements, forecasts, and hindcasts. Measured data sets may be relatively recent, with only a few years of archived measurements. In some cases measurement archives may cover two or three decades, which is comparable to the service life of an offshore wind project.

Existing operational metocean forecast products typically have a forecast horizon of one to two days, although "Wavewatch III" operational wind and wave products have a forecast horizon out to 180 hours (7.5 days). Some forecasts retain archives of their "nowcast" products (which are based on present-time analysis and thus the most accurate), but such archives have been maintained for just a few years. In some cases "nowcast" products are routinely discarded, which represents a lost opportunity.

For estimating extreme storm conditions that might occur during the service life of an offshore wind project, two to three decades of numerical model "hindcast" results are needed. Hindcast products estimate what metocean conditions would have been like based on actual past measurements of driving parameters such as atmospheric pressures and temperatures, while forecast products are based on predicted estimates of driving parameter values in the future.

Existing metocean measurement stations off Virginia are not suitable by themselves to meet the measurement needs of a "bankable" offshore wind resource assessment. They can however provide data points for physically validating any numerical metocean simulation models such as hindcasts and forecasts or any future metocean model that might be developed specifically for offshore wind development.

There are three operational metocean measurement stations on Virginia's OCS, which are mapped in Figure 1. Access to near-real-time data for all three stations is available through the main Web site of the National Data Buoy Center (NDBC), although the wave measuring buoy off Virginia Beach is actually owned and operated by the Coastal Data Information Program (CDIP) of Scripps Institution of Oceanography.

Figure 1: Existing metocean measurement stations on Virginia's Outer Continental Shelf.

NDBC station CHLV2 is part of NOAA's Coastal-Marine Automated Network (C-MAN) and is located on the Chesapeake Light Tower 24 km (13 nmi) east of Cape Henry in 12 m (39 ft) water depth. It has been measuring winds and non-directional wave spectra since August 1984, archiving 10-minute average wind speed every hour. Starting in June 1989, 10-minute average wind speeds have been archived continuously. Wave measurements ceased in December 2004, and sea surface temperature measurements ceased in August 2003. The following metocean instruments still operate: wind speed and direction at an anemometer height of 43.3 m (142 ft) above mean sea level (AMSL), atmospheric pressure at 23.4 m (77 ft) AMSL, and air temperature at 22.3 m (73 ft) AMSL.

NDBC station 44099 is a Scripps Institution of Oceanography Waverider buoy located 18.5 km (10 nmi) east of Cape Henry in 19 m (62 ft) water depth. It has been measuring directional wave spectra and sea surface temperature since June 2008. Air-sea temperature difference is an important input parameter for numerical modeling of the wind shear profile near the sea surface, and this can be calculated using the air temperature measurement at CHLV2.

NDBC station 44014 is a 3-meter discus buoy moored near the continental shelf edge in 47.5 m (156 ft) water depth, 120 km (64 nmi) east of False Cape. It has been measuring winds, waves, air temperature, sea surface temperature, and atmospheric pressure since October 1990. The wind sensor ceased functioning in March 2010 and was replaced during NDBC's service visit in April 2011. This station also has an acoustic Doppler current profiler (ADCP) that has been measuring mean water velocity 3.8 m below the sea surface since March 2010. Short-range visibility data (out to 1.6 nmi from buoy) were archived from July 1991 to December 1994.

Section 3. State of the Art in "Bankable" Offshore Wind Resource Estimation

Types of Wind Measuring Instrumentation

A typical anemometry mast will have several anemometers (devices to measure wind speed) installed at different heights on the mast, and at least two wind vanes (devices to measure wind direction). These will be connected to a data logger, at the base of a mast, via screened cables. In the absence of an alternating current power supply (as is the case at most offshore sites), the wind measuring system is battery operated, with battery charging via solar panel or small wind turbine.

For some systems, particularly in cold climates, the measurement of the temperature is important to assist with detection of anemometer icing. Temperature also factor into the calculation of air density for wind power density estimates. Temperature also should be measured at multiple levels in order to calculate heat flux, which is an important factor in applying numerical models to extrapolate wind speed at elevations higher than the anemometer.

Remote sensing technologies are being developed rapidly and likely to be more widely used in the near future. These are ground-based upward-looking or outward-looking devices that can measure wind velocities at a range of elevations without the need for a conventional anemometry mast. The two main types of remote sensing wind profilers for wind energy applications are:

- SODAR (SOund Detection And Ranging), which emits and receives sound and from this infers the wind speed at different heights using the Doppler shift principle; and

- LIDAR (LIght Detection And Ranging), which also uses the Doppler shift principle, but emits and receives light from a laser.

According to Reference12, profiling SODARs are three to four times less costly than profiling LIDARs, but they show five times greater deviation when compared with cup anemometers, and suffer from poor availability at high wind speeds due to acoustic beam bending. They also are too large to be mounted on buoys. Therefore this report focuses on LIDAR units.

Signals that would typically be recorded for each anemometer (or at each target elevation for a LIDAR unit) are as follows:
- mean (ten-minute average) wind speed;
- maximum (moving three-second average) gust speed;
- true standard deviation of wind speed; and
- mean wind direction.

In recent years, it has become standard practice to download data remotely, via either radio modem or a satellite link. This approach has made managing large quantities of data more efficient and less costly than manual downloading by service personnel. It also has the potential to improve data availability, since failed or faulty sensors can be detected in near real time.

The key analyses to be performed on the mean wind speed and direction data is to develop a long-term (20- to 30-year) probability distribution of wind speeds and a wind direction rose. Other meteorological inputs to a project's annual energy production analysis are the long-term site air density and site turbulence intensity (as characterized by the standard deviation of wind

speed during a 10-minute averaging period). While still important, these are of secondary influence on the estimated energy production of a wind project, and their derivation is not considered further in this report. It should be noted, however, that the turbulence intensity is very important in determining the aerodynamic loading regime on the rotor and drive train of a turbine and influences the life expectancy of the rotor blades and gearbox.

Using Short-Term Measurements to Develop a Long-Term Resource Estimate

Even on land there is a general lack of wind data measured directly within a project site at the hub height of the turbine. This is because wind projects have a service life of 20- to 30-years, while developers only have a 1- or 2-year window of opportunity to undertake site-specific measurements. Such a short measurement period does not necessarily represent the long-term wind climate in which a project must operate.

As described in the previous section, the NDBC meteorological station on the CLT has been measuring wind speed and direction at 43 m above sea level since 1984. This represents more than 25 years of quality-controlled data at a fixed location. One may well ask if these data can be directly used for offshore wind project development off Virginia.

This would require two spatial extrapolations, as shown in Figure 2: a vertical extrapolation from the anemometer height of 43 m to the expected turbine hub height which is likely to be 90 or 100 m above sea level, and a horizontal extrapolation from the CLT location to the wind project site, which is likely to be a few tens of kilometers (in the range of 10 to 50 km) east of the CLT. The next two pages describe European observations of the spatial variability in both vertical extrapolation to turbine hub height and horizontal extrapolation to turbine site.
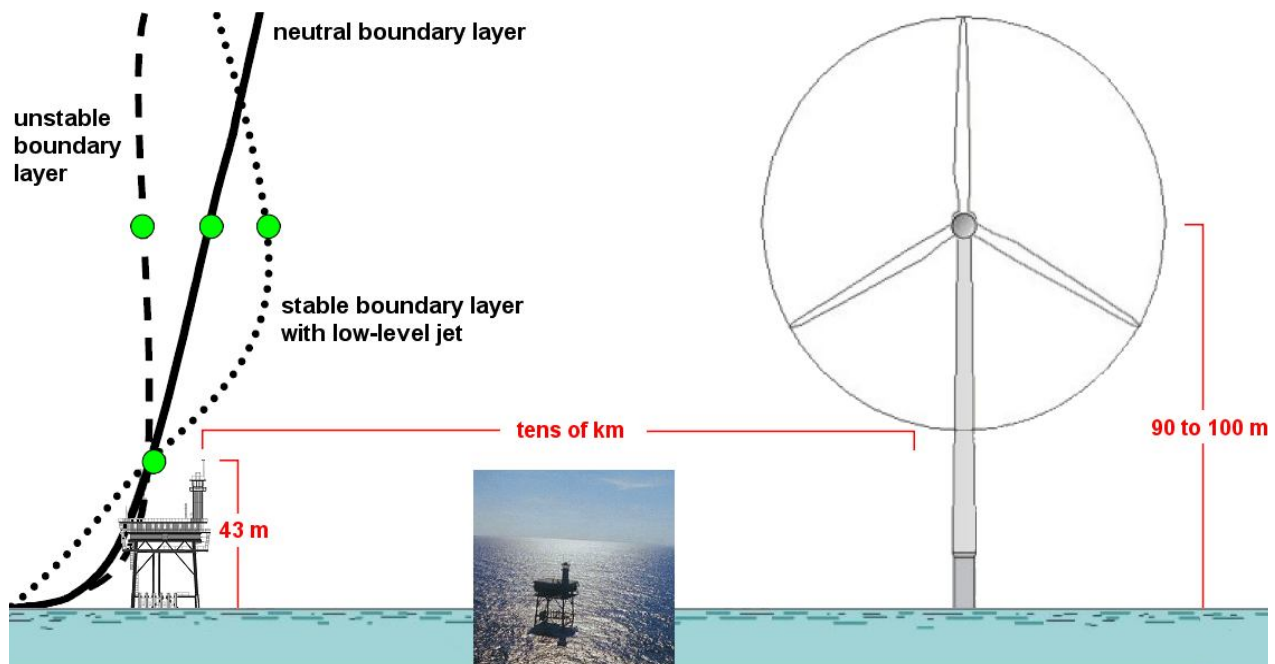

Figure 2: Uncertainties introduced by direct extrapolation of Chesapeake Light Tower data to likely commercial offshore wind turbine sites off Virginia. See text for explanation.

For feasibility-level analyses, the vertical profile of wind speed can be described by a simple power law ratio between the speed measured at one height and the extrapolated speed at turbine hub height, as was done by VCERC for its initial wind studies (Reference 2). Such an estimate is not bankable and VCERC analysis suggests that the uncertainty in power law extrapolation is in the range of 20% to 25% (Reference 13). A more sophisticated approach would be to use a meso-scale or micro-scale numerical model to simulate the vertical profile of wind speed by factoring in sea surface roughness, heat flux, and the height of the boundary layer. As shown in Figure 3, however, comparison between such models and tall mast measurements at the FINO-1 met tower off Denmark suggest they still are not sufficiently accurate for project financing.
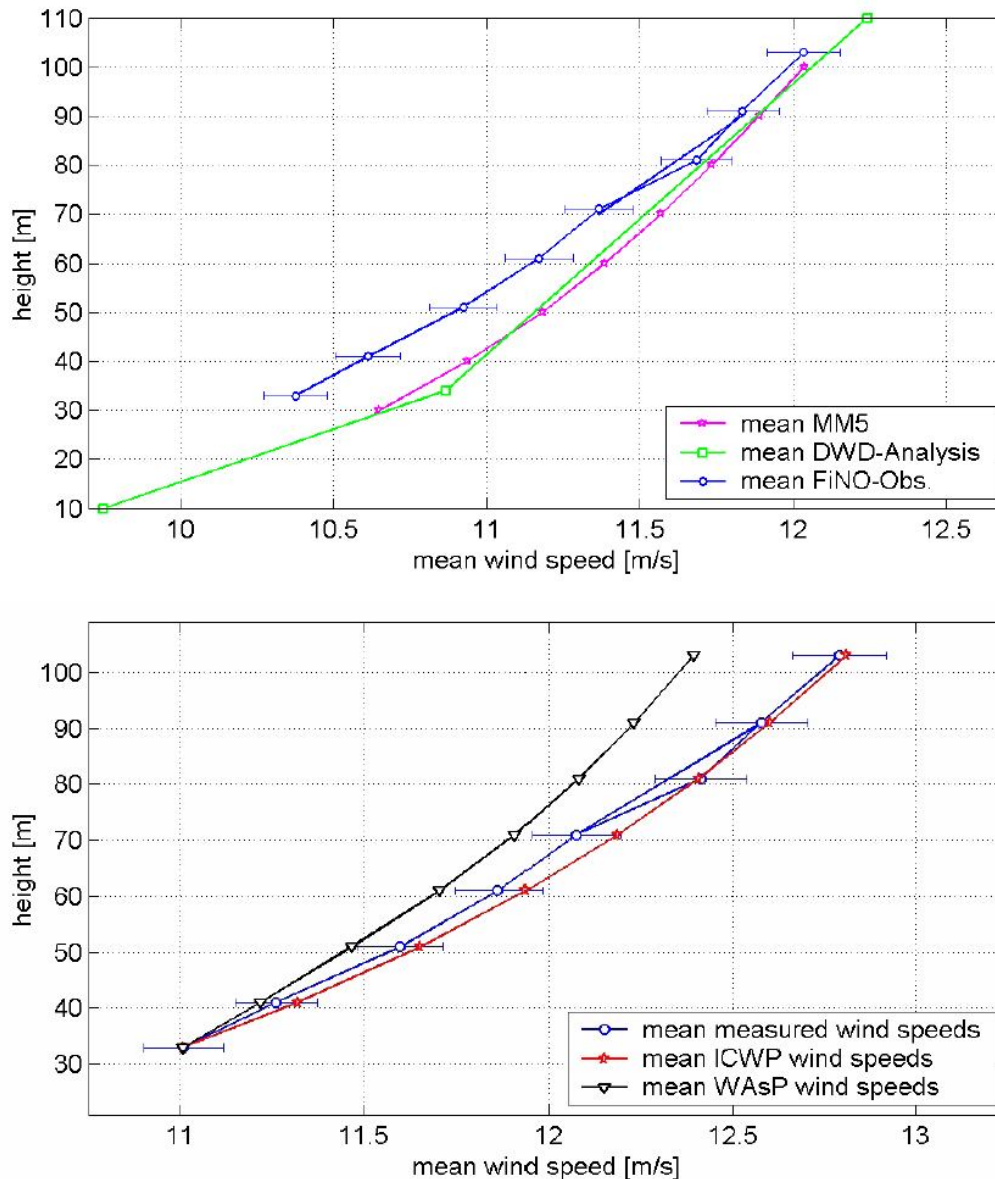

Figure 3: Comparison between the average wind speed profile measured at FINO-1 and numerically simulated profiles using two different meso-scale models (MM5 and DWD in upper graph) or a commercial micro-scale model (WAsP in lower graph). The research micro-scale model, ICWP, shows promise but is not validated for project financing purposes (Reference 14).

The aerial photograph of the CLT in Figure 2 suggests that this ocean area is a homogeneous environment and that horizontal extrapolation of the CLT anemometer data might be possible. Conceptually, it might appear that offshore wind resources ought to be relatively easy to predict, due to the lack of topography and obstacles. Again, however, research in Denmark suggests that wind resource estimation at offshore sites is more complex than usually believed.

Variable sea surface roughness under different wave conditions, atmospheric stability, and the growth of the boundary layer with increasing distance from shore complicate the situation, but also the land–sea discontinuity can have affects far offshore. In this flow regime, the wind speed increases more rapidly with height than predicted by boundary layer theory. It should be noted that these deviations, although caused by the coastal discontinuity, have been observed as far offshore as 100 km (Reference 15).

The width of the coastal influence zone, and the wind's vertical (shear) and horizontal gradients within that zone, depend on atmospheric stability, with wind speeds adjusting more slowly (creating a wider zone of coastal influence) under stable atmospheric conditions. Modeling suggests that within the coastal influence zone, wind speeds at typical turbine hub-heights can change by up to 2 m/s over the horizontal extent of a large wind farm, depending on atmospheric stability (Reference 16).

Finally, meso-scale phenomena such as sea breezes, low-level jets, and roll circulations, also affect the wind speed and turbulence experienced by wind turbines in the offshore coastal zone. Reference 13 describes research at Rutgers that shows the zone of sea-breeze influence can extend up to 50 km offshore. Of particular concern is divergent, weak-wind zones associated with sea breeze circulation cells that develop along the Mid-Atlantic coast during warm afternoons, which are most prevalent during summer months of peak power demand.

Although CLT wind measurements cannot be extrapolated directly to predict project energy output with bankable accuracy, they represent an excellent reference archive that can be used in the well-accepted "Measure-Correlate-Predict" (MCP) method for predicting long-term wind speed distributions at a project site when only short-term measurements are available at that site. The MCP procedure as it might apply off Virginia is illustrated in Figure 4. On-site data would be measured for a short term (at least one year) on a proposed project site using a calibrated and traceable vertical profiling LIDAR on either a fixed platform or a buoy. As documented later in this section, this type of equipment can provide wind speed measurements directly on the project site and across the entire span of the turbine rotor swept area, so no spatial extrapolations would be needed. If it can be established that there is good correlation between the short-term site data and data measured concurrently during the same period at the reference station (the CLT), then a linear regression or other statistical comparison (Reference 17 describes different methods) can be used to re-create (or "predict") what the long-term history of wind speeds would have been at the project site during the archive period of the reference station (since 1984 at the CLT).

Note that the MCP procedure assumes that the offshore wind climate for the past 25 years will not change substantially during the next two to three decades. Analysis of wind measurements archived for the past ~60 years suggest long-term decreasing wind speed trends in the coastal Mid-Atlantic and Southeast regions (References18 and 19). The Southeast trend reversed in 1991, but wind speeds there still are below their 1940s and 1950s levels (Reference 19).
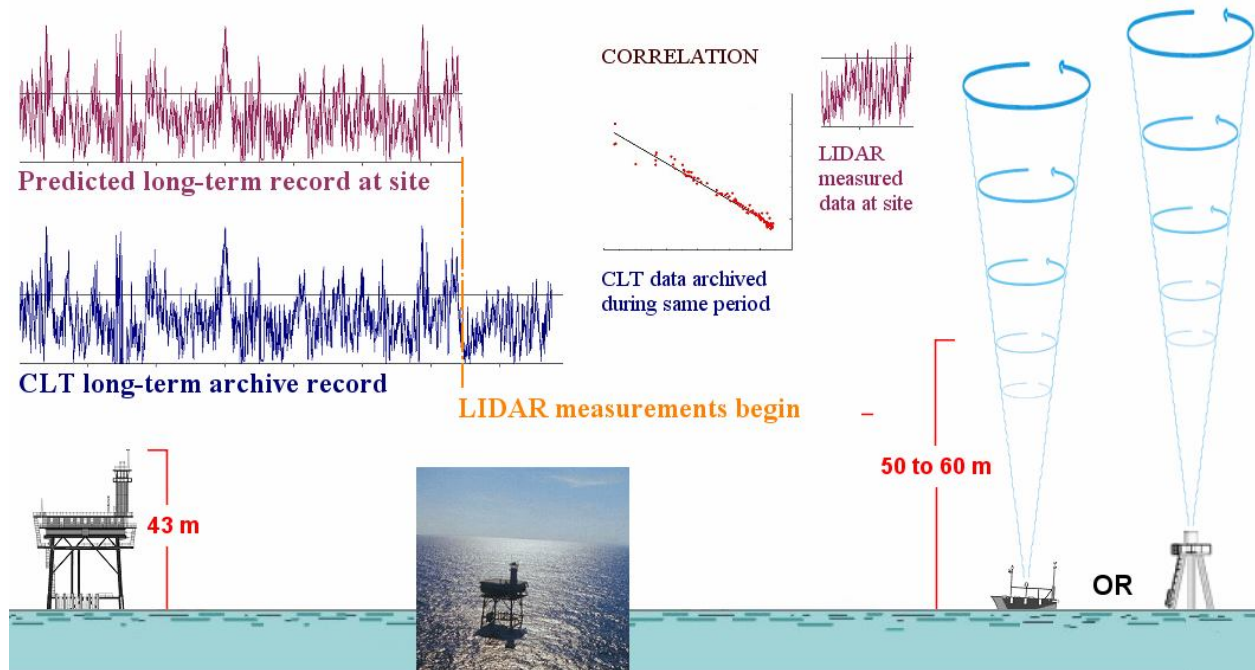
Figure 4. Measure-Correlate-Predict (MCP) resource assessment procedure as it might apply to commercial offshore wind project development off Virginia. The CLT provides a long-term reference station, and its most recent measurements would be correlated to a vertical-profiling LIDAR (either on new fixed tower or moored buoy). The correlation coefficient between the two records would be used to "predict" what the long-term wind speed would have been at the project site had the LIDAR been on site for the same length of time as the CLT record. The lowest elevation profiled by the site-based LIDAR (50 or 60 m range gate) should be used for correlation purposes, as this would be closest in elevation to the 43 m anemometer height at the CLT. Since the LIDAR units measure additional elevations up to 150 m and higher, there would be no need for vertical extrapolation to turbine hub height. See text for additional explanation.

Requirements for a suitable long-term reference station described in Reference 20 are:

1. The archived reference data set has at least a one-year overlap in time with the short-term measurements on site

2. It can be demonstrated that the data has been recorded using a consistent system over the period of both the concurrent and longer-term data. This should include consideration of the position and height of the mast and the consistency of equipment used, all of which have been well maintained at the CLT by the National Data Buoy Center.

3. No potential changes to exposure of the reference station met mast. It is for this reason that wind turbines (demonstration or commercial) should be excluded from within a 5 km radius circle around the CLT. Any changes to the measurement equipment or surrounding exposure will render it useless as a reference site.

4. The Pearson correlation coefficient (r^2) between the short-term measured data at the project site and the concurrent archived data should be at least 0.8.

Use of Fixed Vertical-Profiling LIDARs to Improve Project Financing Terms

Appendix A to this report summarizes the specifications of different commercially available vertical-profiling LIDAR units and presents some performance comparisons with conventional cup anemometers. Given the relative newness of this technology as compared with conventional anemometers, this section examines the potential of vertical-profiling LIDARs to improve the "bankability" of a wind project by reducing the uncertainty in hub-height resource assessment.

As exemplified by the FINO-1 platform off Denmark, to construct an offshore anemometer mast that extends fully to the optimal hub height of modern offshore wind turbines, which is likely to be 90 or 100 m, would cost more than $10 million. This is because substantial mast structure is required to prevent swaying of the mast top. Because of the small platform deck area, the mast must be cantilevered from the platform base without guy wire support. For this reason, it has become accepted practice to construct offshore masts to 2/3 of hub height, as has been done for the Cape Wind project in Nantucket Sound, where the meteorological mast extends to just 60 m, whereas the proposed turbine hub height is 90 m.

A comprehensive field evaluation of cup anemometers and vertical-profiling LIDARs in flat coastal terrain has been reported by the Risoe National Laboratory in Denmark (Reference 21). This study compared the annual energy production (AEP) estimate of a 2 MW turbine with a hub height of 100 m, as derived from four different measurement sources, with the following results for uncertainty in the 90% confidence intervals for AEP estimates of Annual Energy:

- Class 1 cup anemometer at 100 m elevation (hub height measurement) on a guyed mast. Benchmark (best achievable) AEP uncertainty: ±0.5%

- Cup anemometer at 80 m elevation, with measurement-driven extrapolation to hub height using WAsP micro-scale numerical model with either default heat flux or site-specific measured heat flux. AEP uncertainty: -1.7% to -2.8%

- Cup anemometer at 60 m elevation, with measurement-driven extrapolation to hub height using WAsP micro-scale numerical model with either default heat flux or site-specific measured heat flux. AEP uncertainty: -8.1% to -8.5%

- Vertical-profiling LIDAR (Leosphere WindCube) traceable to calibrated Class 1 cup anemometer, measuring at 100 m target height. The largest source of error for such LIDARs is the range estimate to the target height, causing the greatest wind speed error when the vertical gradient in wind speed (i.e. shear) is greatest (stable atmospheric conditions). AEP uncertainty: ±2.5%

These results indicate that calibrated and traceable WindCube vertical-profiling LIDARs in flat terrain yield AEP uncertainties for 100 m hub height comparable to those from cup anemometers at 80 m elevation, and significantly better than those from cup anemometers at 60 m elevation.

German field tests (Reference 22) have yielded similar results, with WindCube deviation from cup anemometer measurements being less than the inherent uncertainty in the cup measurements themselves. The WindCube pulsed LIDAR also was shown to have better agreement with cup anemometers than the ZephIR continuous-wave LIDAR (see Appendix A for details). Good agreement with mast-based cup anemometers also has been reported for the pulsed Galion LIDAR profiler (References 23 and 24; see Appendix A for details).

A critical question is whether vertical-profiling LIDAR data will be acceptable for commercial project financing on the same terms as cup anemometer data. Until formal standards for LIDAR-based resource assessment are developed (see Reference 25 for status), projects must be assessed on a case-by-case basis. As stated in Reference 21:

> It is very likely that with coming improvements well-documented LIDAR
> measurements for hub-heights above 60 m in flat terrain will be similar in
> precision to many "in field" cup anemometer set ups. Furthermore, the avoidance
> of vertical extrapolation is likely to reduce the overall AEP estimate uncertainty.

To understand how reduced uncertainty translates into improved project financing terms, it should be noted that resource assessments include Monte Carlo simulation-based statistical analyses that incorporate a relatively small number of key uncertainties, which area assumed to each have a normal probability distribution. The resulting AEP has an overall probability distribution that associates energy production levels with a probability of those levels being exceeded during a specified time period, such as one year, ten years, or the service life of the project (see Figure 5). For example, a P90 of 110 GWh/year means there is a 90% probability of the project producing an annual average of 110 GWh during the specified time period. From the perspective of a bank or investor, this means that there is only a 10% risk that the project will produce less than this amount.
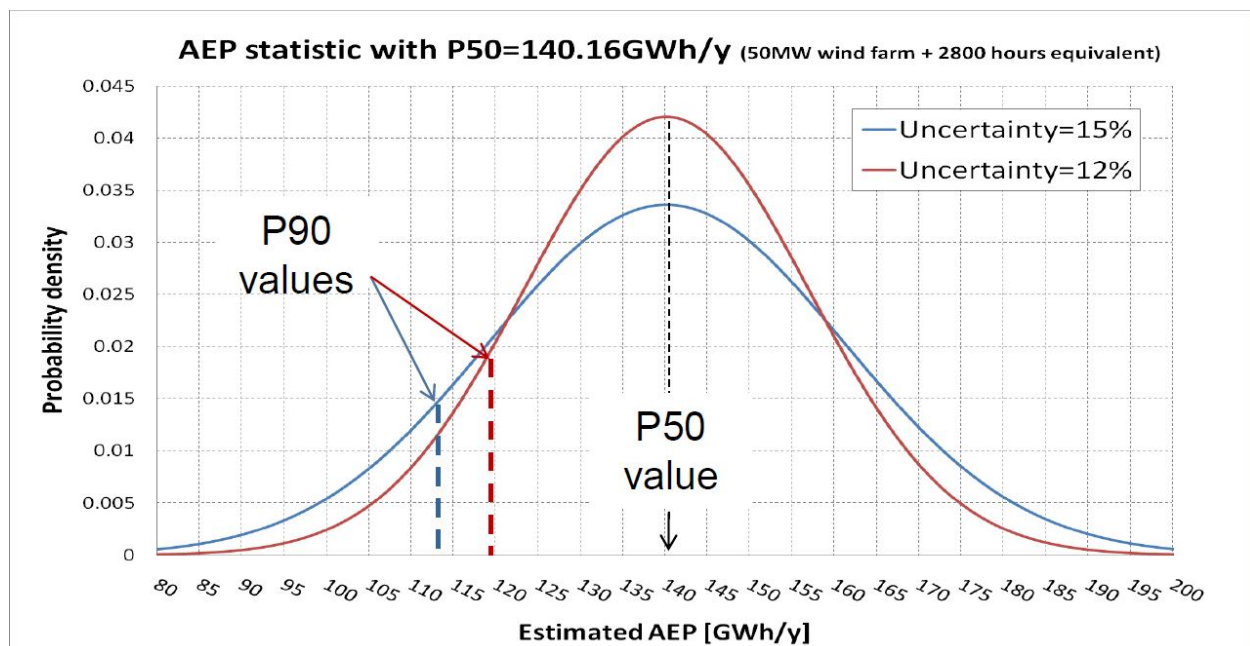

Figure 5. Annual Energy Production (AEP) probability distribution for a hypothetical 50 MW wind project with two levels of overall uncertainty, which include resource uncertainties (the primary focus of this report) as well as uncertainties in turbine performance and long-term reliability. The objective of any VOWDA-facilitated metocean measuring program off Virginia will be to reduce uncertainties associated with vertical extrapolation of wind speed profiles to hub height and horizontal extrapolation of wind speed data from the CLT or a project-centered met tower to different turbine locations that may be up to 10 or 15 km away from the met tower site for a project of several hundred megawatts. Source of graphic: Reference 26 .

Based on such a statistical approach, Figure 7 illustrates how reduced uncertainty yields a larger value of P90 energy production, which thus translates into a higher revenue stream. In this example, both cases have the same mean (P50) annual energy production, but when the uncertainty around that value decreases from ±15% to ±12%, the annual energy production increases by more than 5 GWh annually. This represents an increase in the guaranteed revenue stream against which a project can secure debt financing, enabling a greater amount of the project to be financed by debt and reducing the amount of required equity investment (which costs more than debt and is not tax deductible).

Note that the uncertainty analyses presented in typical wind energy resource assessments assume that the turbines will perform according to the manufacturer's power curve and will have a minimum availability. The turbine's power performance and availability are usually covered by specific warranties from the turbine manufacturer. Any consideration of the uncertainty contributions from these parameters requires third-party review of the turbine performance curves and the turbine supply contract, both of which are generally outside the scope of this report, which is focused solely on the acquisition of bankable wind speed data to inform the wind energy resource assessment.

Wind energy in general and offshore wind in particular is fundamentally different from other generation in its risk profile, in both resource and non-resource aspects. A fossil fuel or conventional hydro generation plant involves a well behaved resource exploited by a small number of turbines in an interior space close to operation and maintenance infrastructure. In contrast, as stated in Reference 25, "wind power entails the exploitation of a highly variable and intermittent resource which has characteristics that cause stress and damage by a large number of highly dispersed assets in locations that present access challenges." This is particularly true of offshore wind.

As stated in the previous section of this report, physically validated numerical metocean models can be used to reduce uncertainties associated with construction cost overruns due to "waiting on weather" during installation, accumulated fatigue damage, offshore access for timely maintenance and repairs, and extreme event survival. Existing measurement station on Virginia's OCS can be used to validate some aspects of such models, and the metocean measurement equipment recommendations made in this report also can support such physical validation. The primary focus of the next two sections, however, is the establishment of metocean measuring equipment that will facilitate offshore wind resource assessments to support annual energy production estimates and the associated guaranteed revenue stream that developers can offer to secure low-cost project financing.

Buoy-Based Vertical-Profiling LIDAR and Fixed Volume-Scanning LIDARs

Two LIDAR profiling units have been incorporated into buoys. One is the QinetiQ ZephIR and the other is the Vindicator manufactured by "Catch the Wind" of Manassas, Virginia. Although ground test results suggest that the Vindicator is not as well correlated with cup anemometers as the WindCube or Galion (Reference 27; see Appendix A for comparison), the Vindicator has platform motion correction algorithms based on its original use for wind shear sensing aboard in-flight helicopters. This has led to its incorporation in the WindSentinel buoy marketed by AXYS Technologies in British Columbia. Specifications for the buoy-mounted Vindicator unit are given in Appendix A to this report.

Initial sea trials of the WindSentinel buoy off Vancouver were conducted in November and December of 2009. Buoy-mounted LIDAR wind speeds were compared with readings taken from a stationary LIDAR located 750 meters away on Race Rocks Island (Reference 28). To the principal author's knowledge, results from these trials have not been published. Fishermen's Energy has proposed to use a WindSentinel buoy for resource assessment on its project off the coast of New Jersey (Reference 29).

QinetiQ, the British company that developed the ZephIR vertical-profiling LIDAR, also has developed a buoy-based version called the SeaZephIR, , which Deepwater Wind has proposed to use for its New Jersey project (Reference 29). This is reported to cost $3 million (Reference 30), and a second SeaZephIR has been ordered for Deepwater's projects off Block Island

The U.S. Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE) has approved the use of these buoy-based vertical-profiling LIDARs on their interim-policy leases off New Jersey, and the New Jersey Board of Public Utilities has determined that these systems will qualify for the rebate that the state granted these developers for offshore wind measurement, even though fixed towers were envisioned when the rebates were first awarded (Reference 29).

If the LIDAR range-finding height uncertainty introduced by buoy motions can be minimized by heave-pitch-roll correction algorithms to the point where these vertical-profiling LIDARs have the same accuracy as their fixed counterparts, then buoy-based LIDARs can make two key contributions to reducing the overall AEP uncertainty for offshore wind projects. First, they can reduce the uncertainty caused by vertical extrapolation of cup anemometer data to turbine hub height from a shorter-than-hub-height mast. Second, being moored by moveable anchors, the buoy can be redeployed around a large offshore lease area, to "map" the horizontal variability of the wind resource. In order to have a sufficiently long measurement record for MCP algorithms and account for seasonal variability, each buoy mooring site should be occupied for one year.

A big advantage of buoy-mounted vertical-profiling LIDARs is their low cost relative to a fixed offshore met tower. Based on estimates quoted earlier in this report, a fixed offshore met tower located in 15 to 20 m water depths, with a 100 m high conventional anemometry mast, would cost at least $6 million. For half this cost, one could purchase and install two buoy-based LIDARs capable of measuring up to the same height. Moreover, these buoys could be ordered, delivered, and installed for one year on two initial monitoring sites, and then moved to two additional monitoring sites, providing the equivalent of four "virtual" met tower records during a 2.5-year period, which is the same length of time that would be required to (1) obtain permits and geotechnical data for a fixed met tower; (2) design, fabricate and install the tower; and (3) collect tower data at one site for one year. Thus for half the cost, two buoys would give a better picture of horizontal wind variability across a large lease area, provided that the short-term buoy records are correlated with a nearby reference station, such as the CLT. Another buoy advantage is that BOEMRE does not require leases for buoy deployments less than 12 months.

Rather than moving buoys around for 12 months at a time, more complete coverage could be obtained by a LIDAR that scans around a three-dimensional volume. The stationary Galion vertical-profiling LIDAR also can be used in volume-scanning mode, but only out to a range of 2 km (Reference 24). This is adequate for viewing velocity deficits in the wake downwind of a nearby turbine (as shown in Figure 6), but not sufficient to map a large offshore lease area.
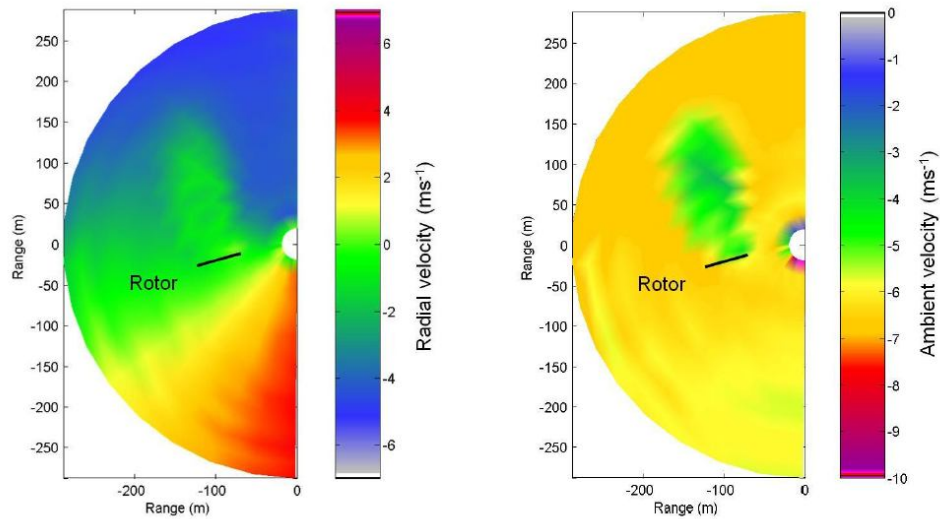
Figure 6. Horizontal slice through a Galion volume-scanning LIDAR measurement image showing a distinct wake downwind of a wind turbine rotor (Reference 24).

The National Renewable Energy Laboratory has evaluated a longer range, volume-scanning LIDAR operated by NOAA's Earth System Research Laboratory (Reference 31). Example profiles of wind speed and direction from this study are presented in Figure 7.
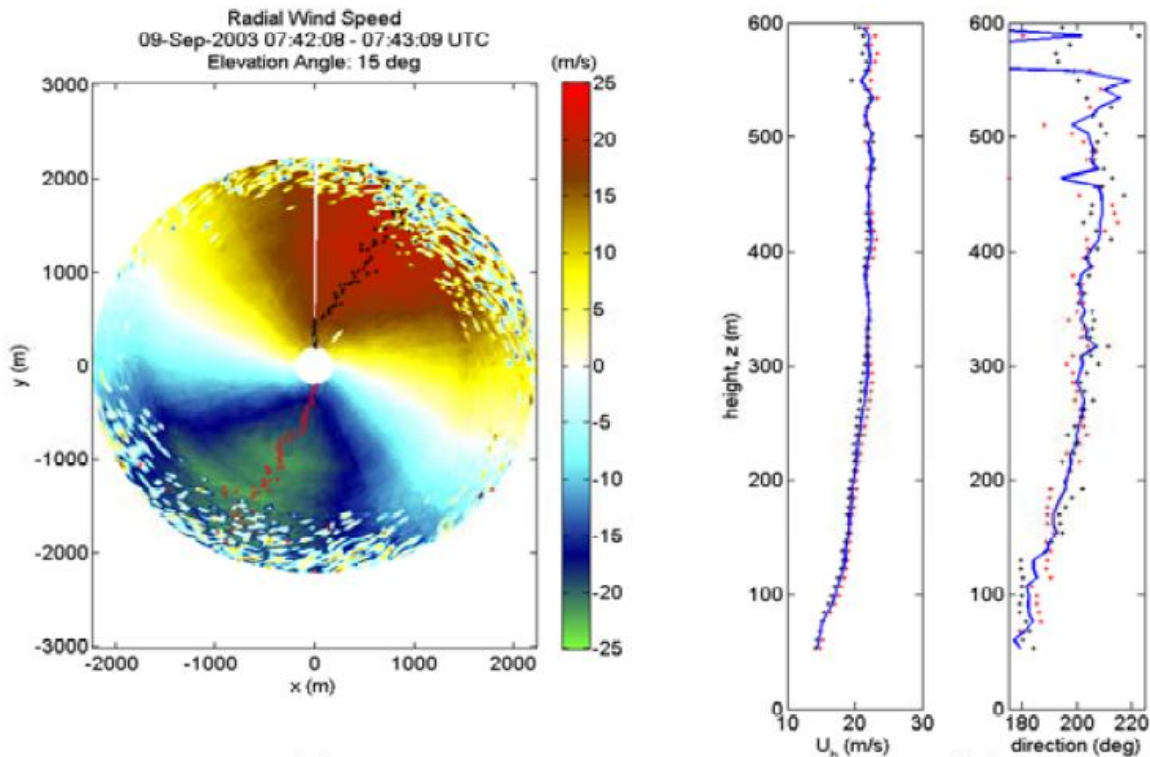

Figure 7. Wind speed and direction profiles measured by NOAA's volume-scanning LIDAR. Because such LIDARS measure radial velocities from the Doppler shift of light reflected from aerosol motion along the laser beam, they are less accurate when measuring winds directed across the laser beam, as shown above by the scatter at heights above 530 m (Reference31).

The only commercial LIDAR unit for long-range volume scanning is the WindTracer offered by Lockheed Martin. Originally developed for wind shear monitoring at airports, the WindTracer has demonstrated clear-air effective ranges of 15 to 25 km (Reference 32).

The wind LIDAR group at NASA Langley Research Center has developed a volume-scanning LIDAR that is sufficiently light and compact that it can be flown aboard research aircraft for characterizing three-dimensional wind fields in a hurricane or severe storm at a safe stand-off distance (Reference 33). Its dimensions and potential performance specifications compare favorably with the WindTracer (see Appendix B for details). If this NASA technology can be licensed to a Virginia-based business for adaptation to offshore wind, and its potentially superior performance verified in Phase II of the measurement program recommended in Section 5 of this report, it could provide a significant export opportunity.

An example of NASA-Langley's measurement capabilities when used as a ground sensor is illustrated in Figure 8. This was taken from a field campaign for measuring low-level nocturnal jets at a test site operated by Howard University in Beltsville, Maryland (Reference 34). The horizontal wind vector was measured by steering the lidar beam to two perpendicular azimuths at a fixed elevation angle. Each azimuth angle is calibrated to a compass heading. With the wind speed versus altitude measured along both directions, the horizontal wind vector was calculated by vector summing the two components. In the example of Figure 8, the elevation angle was set at 45 degrees, and 250 pulses were averaged at each azimuth. The beam scanner was then steered toward a zenith view to measure the vertical wind vector. A single combined horizontal and vertical wind measurement required 3 minutes for scanner movement and pulse accumulation.

Any program of using the Chesapeake Light Tower to validate less costly alternatives to a tall conventional met mast, such as vertical-profiling and volume-scanning LIDARs, should be informed by the banking and investment community that finances wind projects. During a panel discussion on the future of resource assessment, Gisela Kroess, Managing Director, Project & Commodity Finance, UniCredit Bank AG, told the audience that "the main source of the widely reported 10 percent underperformance of North American wind farms in recent years is due to overestimating wind speeds – a consequence of using flawed methods of measurement and extrapolation" (Reference).

It is therefore recommended that an external advisory panel be established to provide feedback and financial industry guidance on any Virginia-based metocean measurement program that emanates from this report. This panel also should include meteorological scientists representing businesses and laboratories working in wind energy resource characterization and measurement standardization, such as AWS Truepower and GL Garrad-Hassan.
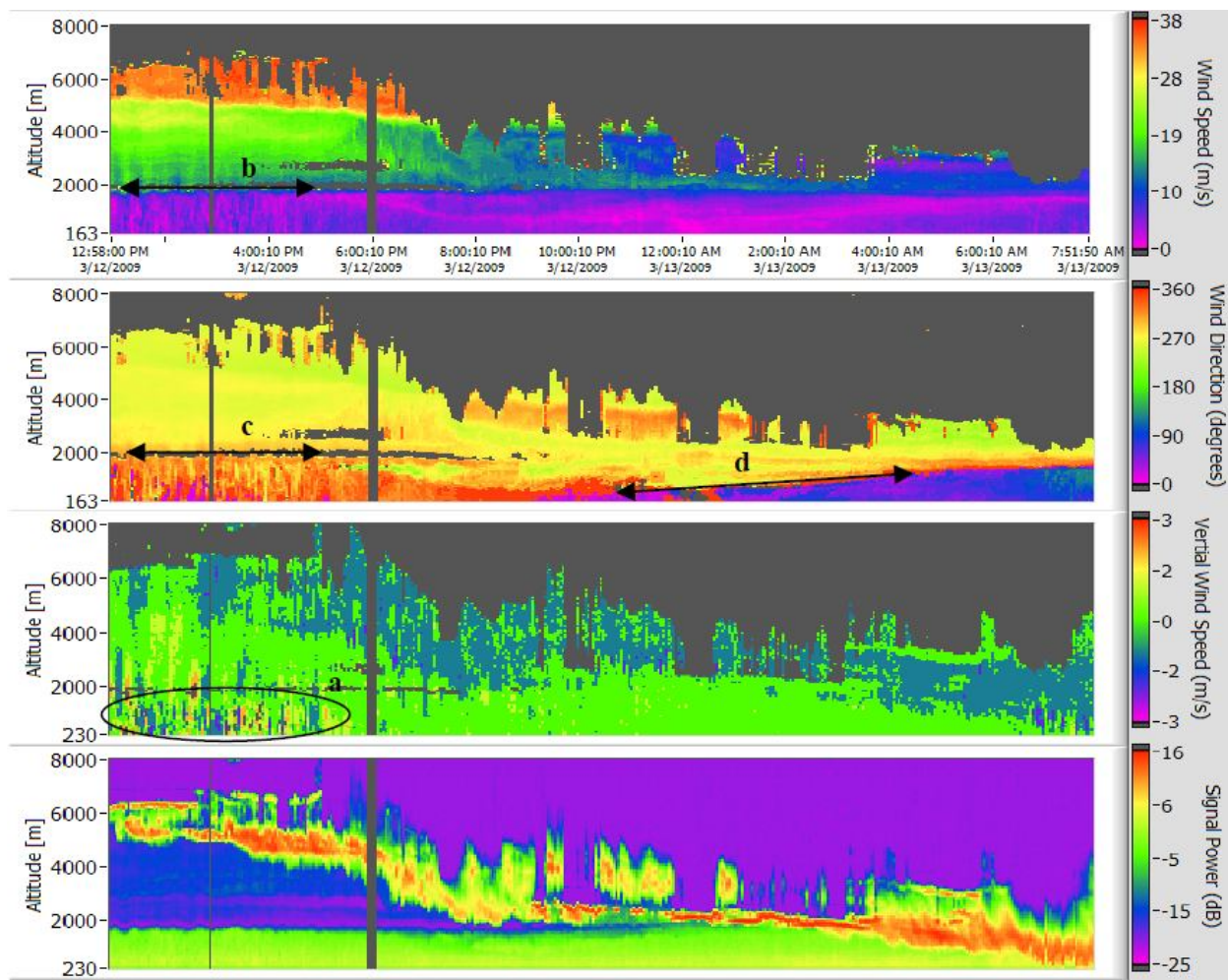
Figure 8. Wind measurements made from NASA-Langley's volume-scanning LIDAR during field testing in Beltsville, Maryland on 12 March 2009. The panels show, from top to bottom, the horizontal wind speed, the horizontal wind direction, the vertical wind speed, and signal power. The signal power panel indicates the presence of clouds and relative density of aerosols. In this data set there is a complex cloud structure that comes to a very low ceiling toward the end of the set. Despite the low cloud cover, wind measurements are made to an altitude of over 2-km. Through the 2nd half of the this data set, a front passed through, bringing rain, as evidenced by associated vertical wind motion. Features of interest are circled: (a) rain-induced vertical wind motion, (b) wind speed shear between the top of the atmospheric boundary layer and the free troposphere, (c) wind direction shear between the top of the atmospheric boundary layer and the free troposphere, (d) change in wind direction as a front passes through.

Section 4. Existing Uses and Present Status of the Chesapeake Light Tower

On 17 March 2010, the U.S. General Services Administration (GSA) issued a notice of surplus property determination for the CLT, which is located approximately 24 km (13 nautical miles) east of Virginia Beach (Reference 35). The structure consists of a lantern platform, an upper helicopter landing deck, a middle deck of enclosed machinery space and living quarters covering approximately 1,000 square feet, and a lower, open maintenance deck, supported by four main pilings in a water depth of 11.6 m (38 ft). An outboard profile is shown in Figure 10.
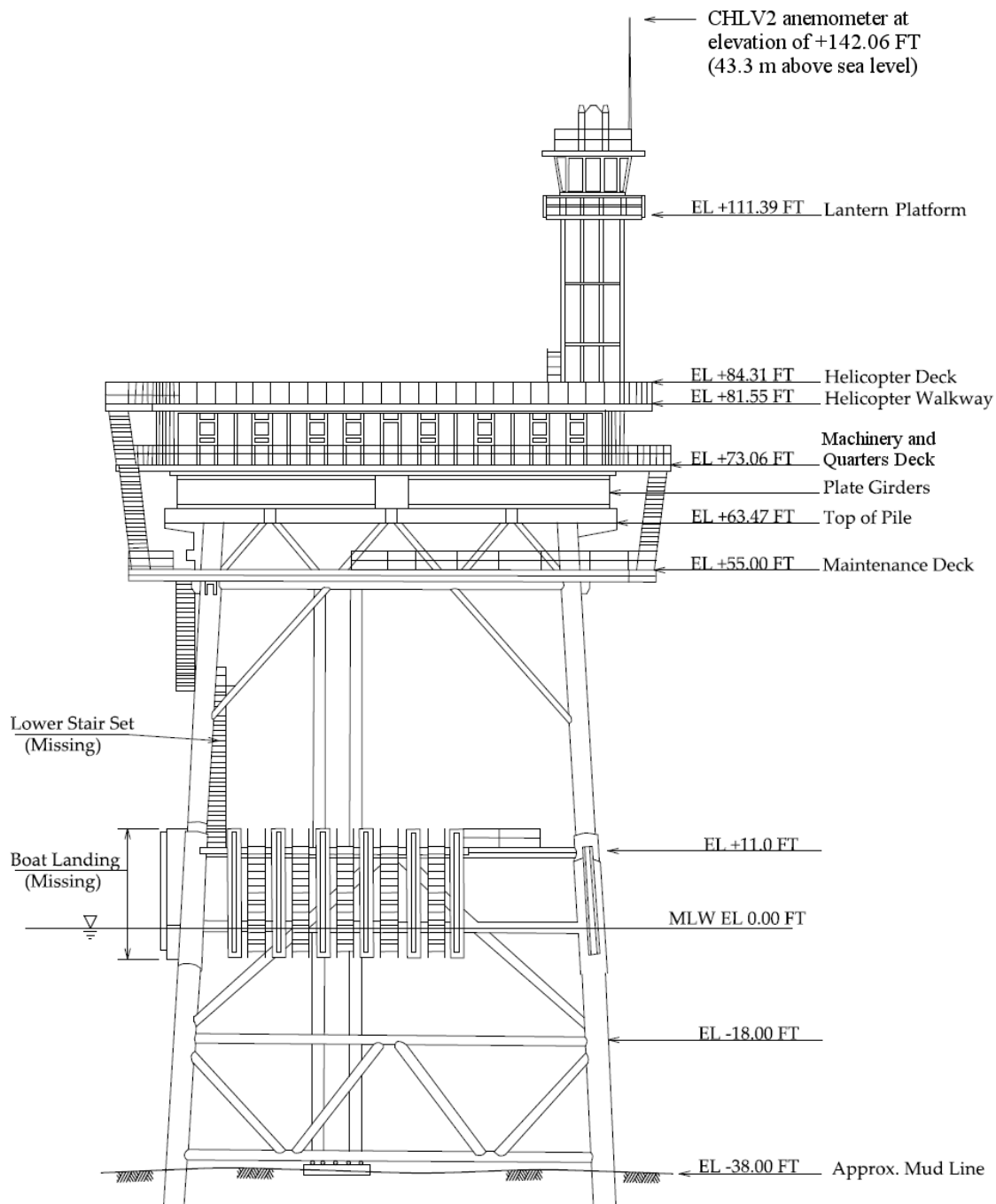

CHLV2 anemometer at
elevation of +142.06 FT
(43.3 m above sea level)

EL +111.39 FT — Lantern Platform

EL +84.31 FT — Helicopter Deck
EL +81.55 FT — Helicopter Walkway

Machinery and
Quarters Deck

EL +73.06 FT

Plate Girders

EL +63.47 FT — Top of Pile

EL +55.00 FT — Maintenance Deck

Lower Stair Set
(Missing)

Boat Landing
(Missing)

EL +11.0 FT

MLW EL 0.00 FT

EL -18.00 FT

EL -38.00 FT — Approx. Mud Line

Figure 10. Outboard profile drawing of Chesapeake Light Tower structure elevations.

The U.S. Coast Guard will continue to maintain its aids to navigation and access for such maintenance, and the National Data Buoy Center will continue to maintain its Coastal-Marine Automated Network (C-MAN) metocean station, which included an anemometer that has been measuring wind speed and direction at an elevation of 43 m above sea level since 1984.

The CLT also serves as an instrumented validation site for satellite measurements of cloud and aerosol microphysics by NASA Langley Research Center (LaRC). The platform is small enough that its "island effect" is negligible, which makes it an excellent site for ground-truth validation of satellite measurements over the ocean (Reference36).

Until now, the Coast Guard has contracted structural inspections every two years at an estimated cost of $50K per inspection. DMME and the City of Virginia Beach have on file the two most recent inspection reports from 2006 and 2008, as well as the most recent underwater survey from 2004. NASA-LaRC performs annual inspections for health and safety and undertakes minor repairs to railings and footings as necessary, roping off any unsafe areas.

Ocean access to the CLT was disabled when the boat landing and stairwell were carried away by Hurricane Isabel in 2003. Access is now possible only by helicopter. Due to deterioration of some supporting structure found in the Coast Guard's 2008 inspection, only helicopters lighter than 9,000 lb are permitted to land. The cost of structural repairs to remedy this condition was estimated to be $1.2 million in 2008 (Reference 37).

In March 2011, the City of Virginia Beach retained Parsons-Brinckerhoff (PB) in Norfolk to conduct a $50,000 structural design analysis of the CLT for supporting a conventional truss-work meteorological mast. The final PB report, dated 02 August 2011 (Reference 38), indicates that a 176-ft three-legged mast can be anchored directly to existing 5-ft-deep plate girders located on the Machinery and Quarters Deck located 14 ft below the Helicopter Deck. This would place the mast top 162 ft above the Helicopter Deck, which has an elevation of 84.3 ft above mean sea level (AMSL). Thus, the tower top elevation would be 246.3 ft (75 m) AMSL.

The rough-order-of-magnitude (ROM) cost estimate for purchasing and erecting this mast on CLT is $550K, which includes all labor and materials for the following structural alterations to support the three-legged mast:

A. Cutting a 9-ft x 9-ft square opening in the Helicopter Deck plating, and an identical 9-ft x 9-ft square opening in the Machinery and Quarters Deck plating, so that the tower can be supported by the 5-ft and 4-ft deep plate girders at the "Top of Tank" level 70 ft AMSL.

B. Welding four stiffener plates and two stub columns to the main outside 5-ft plate girder G1, which will receive two legs of the triangular-section mast.

C. Installing a new 16.5-ft. long, 24" wide-flange beam to support the third leg of the mast. This new wide-flange beam would span the distance between two 4-ft plate girders and include a special connection that bypasses an existing W24x76 beam that supports the Machinery and Quarters Deck joists.

D. Cutting and finishing a local notch in the new wide-flange beam so that the third tower leg can be bolted flush with the web of this beam.

E. Drilling and finishing holes in the two stub columns and in the new wide-flange beam to accommodate six to eight high-strength bolts of 1" to 1-1/4" diameter for each mast leg (18 to 24 total bolt holes).

Figure 11 illustrates the structural alterations listed above and depicts the met mast as it would look when installed on the southwest corner of the CLT. This would be its appearance prior to the construction of a weather envelope as described below the Figure.
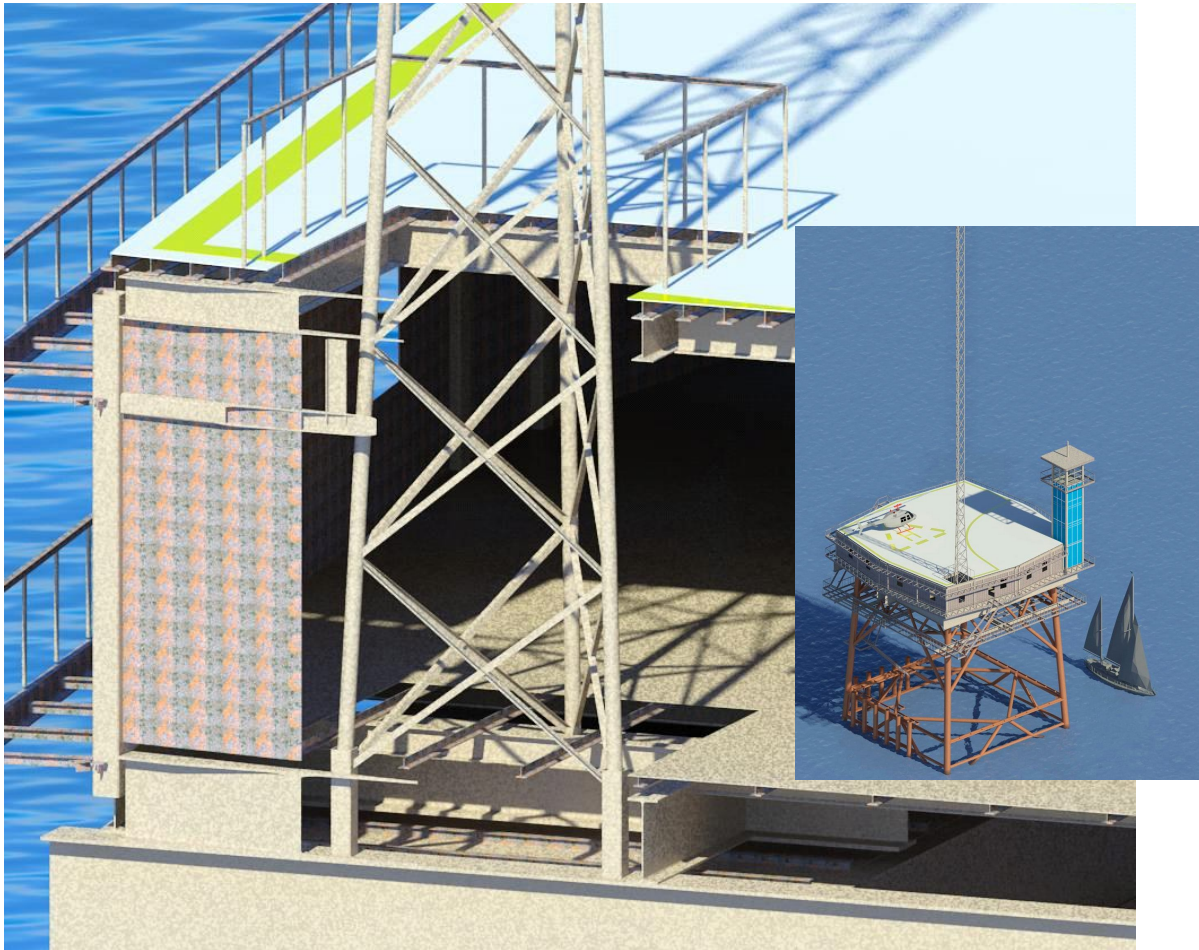

Figure 11. 3D renderings of possible structural alterations for supporting a conventional meteorological mast on the southwest corner of the Chesapeake Light Tower (courtesy of the City of Virginia Beach and Parsons Brinckerhoff).

A jack-up crane barge would hoisting materials onto the CLT and set the mast in place, with the full 176-ft. mast pre-assembled on shore and barged to the CLT. The $550K cost estimate includes mobilization and leasing of a jack-up barge and tower-transport barge, including tow vessels and their operating crews.

After the mast is bolted into place, a weather envelope of metal panels would be constructed on the Machinery and Quarters Deck, around the three sides of the deck cut-outs, so that internal spaces on the Machinery and Quarters Decj are not exposed to the weather. The $550K ROM cost estimate also includes all labor and materials needed to construct this weather envelope.

As of this update, the U.S. Coast Guard is nearing completion of refurbishment work on the four main piles of the CLT and replacement of the boat landing and access stairwell. *Details on the scope of this work and its anticipated completion date will be included in the final version of this update report.*

If equipped with a tall anemometer mast and a high-quality pulsed LIDAR vertical profiler such as the WindCube or Galion, the CLT would provide an excellent fixed platform for field testing of buoy-based LIDARs, which could be moored adjacent to the CLT to validate their ability to yield accurate and repeatable wind profile measurements in wind and wave conditions typical of Virginia's commercial lease area. The CLT also would be a useful platform for avian detection and tracking radar, shipping vessel traffic monitoring radar, and lightning detection sensors.

Plans for testing buoy-based LIDARs must factor in the heavy usage of waters immediately adjacent to the CLT by recreational fishing and diving boats. One possible means of avoiding conflicts with this large user community would be to conduct such demonstrations in the nearby buoy testing area designated on existing nautical charts (Figure 12).

Figure 12. Demonstration of buoy-based LIDARs in the existing buoy testing area 0.5 to 1 nmi north-northwest of the CLT would minimize potential conflict with the fishing and diving boats that now anchor next to the light tower (chart from Reference 39; photo from Reference 40).

Federal Regulatory Considerations

It appears that since 1965, when the CLT was built, the governing regulation for its construction and operation has been the "Rivers and Harbors Appropriation Act of 1899". Section 10 of this Act (33 U.S.C. 403) delegates authority to the U.S. Army Corps of Engineers for review and regulation of certain structures and work that are located in or that would affect navigable waters of the United States, including submerged and above-water structures.

This is consistent with GSA's notice of surplus property determination (Reference 35) indicating that "Use will be regulated by the Corp of Engineers." Therefore, modifications to the CLT, such as installation of a tall anemometry mast, or research activities adjacent to that structure (such as mooring a buoy-based vertical-profiling LIDAR to be validated by the anemometry mast), would be regulated by the Corps of Engineers and may require a Section 10 permit.

Given this regulatory status, BOEMRE has indicated that it is not likely to require that Virginia obtain a right-of-use and easement (RUE) under Subpart J (Rights-of-Use and Easement for Energy and Marine-Related Activities Using Existing OCS Facilities) of the "Renewable Energy and Alternate Uses" rule.

BOEMRE's statutory authority for Subpart J is paragraph 8(p)(1)(D) of the OCS Lands Act (43 U.S.C. 1337(p)(1)(D)). Under this authority, as delegated by the Secretary of the Interior, the then-MMS (now BOEMRE) "may approve activities that use, for energy or other marine-related purposes, facilities that are currently or were previously used for other activities authorized under the OCS Lands Act." The BOEMRE rule also states that Subpart J does not apply to those activities authorized by another statutory authority or other applicable law. Because the CLT falls in this latter category, based on its history and original primary function as a Coast Guard aid to navigation, Subpart J would not apply. BOEMRE has indicated that it is likely to agree with this interpretation and would not impose any other requirements beyond the Section 10 regulatory jurisdiction already held by the Corps of Engineers.

The final version of this update report will obtain definitive documentation of BOEMRE's position on this.

Section 5. Recommended VOWDA Metocean Data Collection Program

<u>Phase I: Conventional Anemometer Mast and Fixed Vertical-Profiling LIDARs on the CLT</u>

Phase I would install a new self-supporting mast on the Chesapeake Light Tower (CLT) to measure wind velocities with both mechanical and ultrasonic conventional anemometers at 45 m, 60 m, and 75 m above mean sea level (AMSL). As summarized earlier, Parsons-Brinckerhoff has evaluated how the existing CLT structure can be modified to accommodate such a mast on its southwest corner (Reference 38).

The southwest corner location for this mast was chosen so as to minimize wake effects on the existing anemometer of the C-MAN station operated by National Data Buoy Center (NDBC). On 21 June 2011, the U.S. Department of Energy convened a multi-agency conference call to discuss the interests of different agencies, including NASA and NDBC, in a public partnership to develop the CLT as a national asset for validating new metocean and environmental monitoring technologies and qualify existing commercial technologies for use in offshore wind project development. In this call, NDBC expressed a strong interest in managing operation of any new meteorological instrumentation installed on the CLT, including data quality control and public dissemination. They also would perform air flow analyses to determine what interference effects the CLT superstructure and mast cross section would have on the wind speed measurements. Assuming the results of their analysis met NDBC's site qualification standards, NDBC would relocate their existing C-MAN instrumentation to the new mast, and this would enable the new mast to be placed right next to the lantern tower.

Locating the new mast next to the lantern tower would provide for safer helicopter access, enabling helicopters to approach from the south or take off to the south, which would otherwise be impossible if the southwest corner location is used as described in Reference 38. The lantern tower might also serve as a robust bracing structure for providing additional stiffness over the lower 36 feet of the 162 feet of mast structure that extends above the Helicopter Deck. This could reduce vibration and swaying of the mast top, possibly enabling the mast to be extended an additional 49 feet to reach a full turbine hub-height elevation of 90 m AMSL.

When Parsons-Brinckerhoff began its structural analysis for the City of Virginia Beach, this alternative was not an option and therefore not considered. An additional $50K would be needed to structurally analyze such a new mast location, adjacent to and just north of the existing lantern tower. The scope of this new study would be to evaluate a new mast based on the Helicopter Deck as close as possible to the existing lantern tower, analyzing two mast heights:

- the first option would be for a 162-ft mast, which would carry the topmost wind sensors to an elevation of 75 m AMSL;

- the second option would be to add an extension pole that would be banded to or otherwise attached along the upper part of the 162-ft tower, thereby extending its height an additional 49 ft, such that the top of the pole would be 211 ft above the Helicopter Deck or 90 m AMSL. One possible source of such an extension pole is www.willburt.com/vmSHDLM.asp. These poles can be up to 164 ft (50m) long, with payload capacities up to 450 lbs (205kg).

If structurally feasible, the above second option would provide four measurement levels (45 m, 60 m, 75 m, and 90 m AMSL), enabling the CLT to be used as a full hub-height reference platform for calibrating and qualifying fixed or buoy-mounted vertical LIDAR profilers.

The cost for this multi-level anemometry mast, including all sensors and structural alterations to the CLT, is estimated to be $550K (Reference 38). Based on European test results that show good accuracy and repeatability for pulsed LIDAR profilers (References 21, 22, and 23), we recommend that Phase I also include two different pulsed, vertical-profiling LIDAR units mounted adjacent to the mast and measuring winds at targeted elevations of at least 45 m, 60 m, 75 m, 90 m, and 105 m AMSL. If the LIDAR unit is not restricted to just five target elevations and has great enough range, then measurements also should be made at 120 m, 135 m, 150 m, 165 m, and 180 m AMSL. This would give a total of ten LIDAR measurement elevations, which is within the capability of at least one commercial system (see Appendix A). Conventional anemometry would measure at the lower three or four LIDAR elevations, depending on the height of the conventional anemometry mast.

In addition to the $550K estimated for acquisition and installation of a new mast on the CLT with conventional anemometers, and $500K for two vertical-profiling LIDAR units to be compared alongside the mast, up to $2.7 million also might be required for repair work, as estimated by two previous CLT evaluations funded by the Coast Guard (Reference 38):

- Casbarian's 2004 estimate of $1.50 million for installation of safety equipment for water-access to the CLT, and restoration of the deteriorated maintenance deck and top of jacket (this did NOT include rebuilding the boat dock and clearing seafloor debris around the CLT sub-structure, which the Coast Guard is now doing).

- Collins' 2008 estimate of $1.20 million to include repair of the girders under the Machinery and Quarters Deck (necessary to accommodate heavier helicopters) and necessary maintenance work at the upper deck levels.

There appears to be duplication of tasks between Casbarian's "restoration of the deteriorated maintenance deck and top of jacket" and Collins' "necessary maintenance work at the upper deck levels." Reference 38 indicates further duplication in that each of the above estimates includes an equipment and vessel mobilization cost of $300K to $500K, which also is duplicated in the $550K estimate for acquisition and installation of a new conventional anemometer mast. Eliminating duplication and assuming that all structural work can be accomplished by a single mobilization cost of $500K, the total ROM budget for Phase I is estimated to be $3 million. A cost breakdown for this total is given in Table 1 on the next page.

This Phase I setup will give Virginia a full vertical profile measurement capability to begin correlating with the climatological archive at the NOAA C-MAN station that has been measuring winds at 43.3 m above sea level since 1984, assuming that the transfer of the C-MAN station to the new mast is carefully managed by the NDBC. After one year of operation, these new data can be used to perform a preliminary analysis of optimal rotor swept area to identify appropriate turbine models well matched to the vertical profile of offshore wind speeds on Virginia's OCS. Phase I should be targeted for installation on the CLT by the end of September 2012, such that one year of data would be available for analysis by October 2013.

**Table 1. Cost and Schedule Estimates for VOWDA Metocean Program Phase I:
CLT Structural Refurbishment and Metocean Instrumentation Upgrade**

	Cost	Schedule
Structural Refurbishment Tasks		
USCG rebuilding of boat landing and clearance of underwater debris around CLT base	none to Virginia	ongoing
Structural engineering study of carrying new mast to 90 m ASL and erecting immediately adjacent to lantern platform	$50K	Jan-Mar 2012
Repair of girders under Machinery and Quarters Deck and needed maintenance work on upper deck levels	$1,800K	Apr-Sep 2012
Marine equipment mobilization *	$500K	Apr-Sep 2012
Metocean Instrumentation Upgrades		
Install new meteorological mast with conventional anemometers at 45 m, 60 m, 75 m, and 90 m ASL	$150K	Jul-Sep 2012
Install two vertical-profiling, pulsed LIDAR units	$500K	Jul-Sep 2012
TOTAL COST:	**$3,000K**	

* In addition to supporting basic structural refurbishment, same mobilized equipment would support transport and installation of new meteorological mast

Phase I also will provide a reference baseline of conventionally measured and fixed LIDAR wind speed profiles that can be used to demonstrate the accuracy and reliability of floating buoy-based LIDARs and of fixed volume-scanning LIDAR at large horizontal offset distances. Having the ability to validate at-sea performance of these two advanced technologies would give offshore wind project developers confidence in such remote sensing technologies for accurately assessing the offshore wind resource at many locations around an offshore project site without having to install multiple conventional anemometry masts.
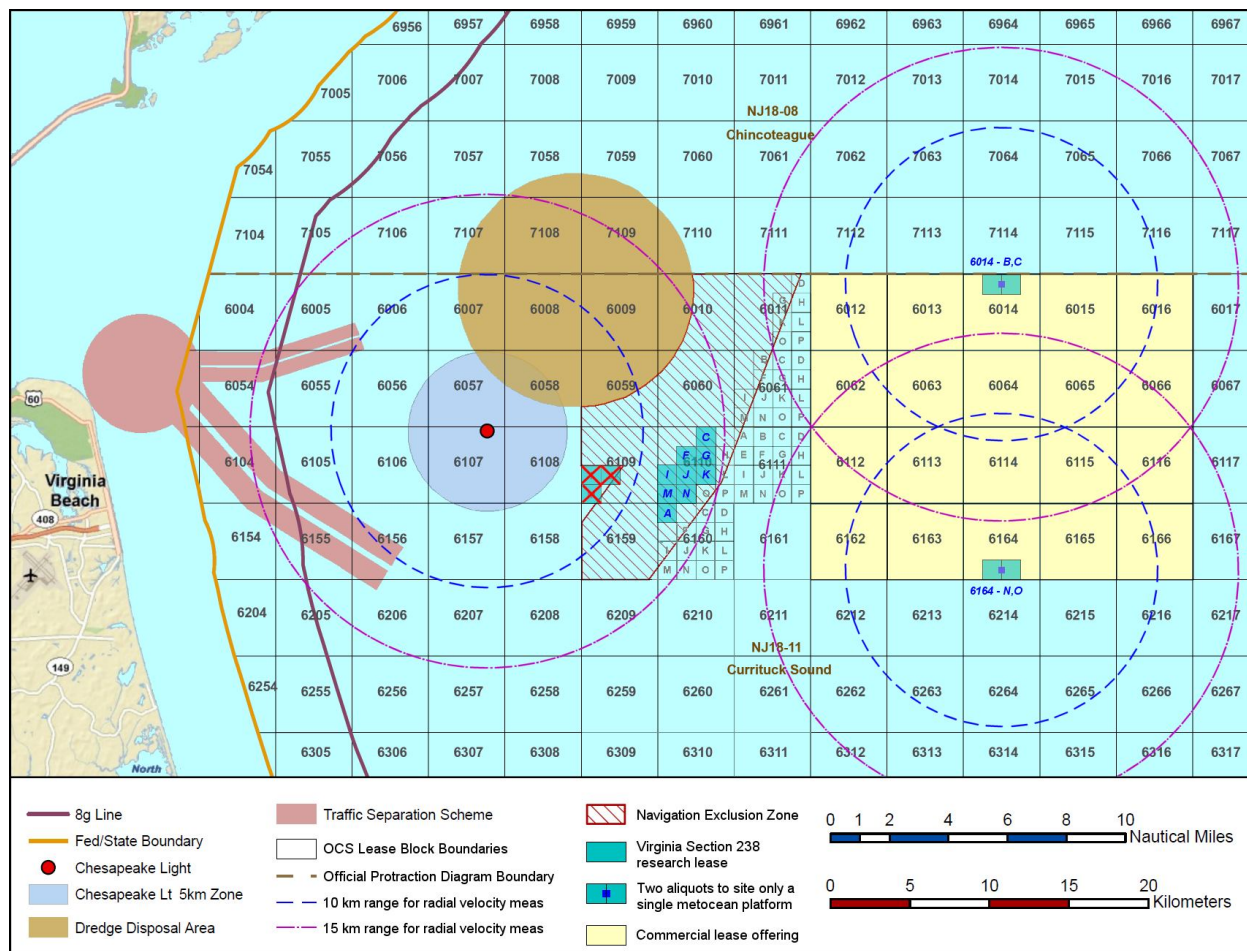
After new vertical-profiling buoy systems or long-range volume-scanning LIDARs have been qualified through advanced technology demonstrations as described above, the CLT Phase I setup can be used for standard commercial system validation and periodic revalidation.   The fee for a 30- to 60-day validation or revalidation test of a LIDAR wind profiling buoy might be in the range of $50K to $100K. The BOEMRE Draft Environmental Assessment for the Mid-Atlantic Wind Energy Areas (Reference 41) estimates that a total of 25 meteorological buoys could be deployed for offshore wind characterization off New Jersey, Delaware, Maryland and Virginia, suggesting that validation and revalidation fees could be a significant revenue stream.

Most importantly, Phase I will preserve the CLT as a long-term climatological reference station for offshore wind project developers throughout the Mid-Atlantic region. With C-MAN stations no longer operating at Ambrose Light, Diamond Shoals Light, Frying Pan Shoals Light, and Savannah Light, the CLT is the *only* operational fixed measurement platform with a multi-decade record of wind speeds on the Atlantic OCS, which all developers will need in order to measure-correlate-predict annual energy production from short-term project site measurements.

Phase II: Field Trial of a Fixed Volume-Scanning LIDAR on an Oceanfront Hotel

WindTracers have shown effective ranges of 15 to 25 km in the clear, dry air of Colorado (Reference 32), although many details of those tests have not been published. WindTracer performance offshore has not yet been verified, although a coastal trial is planned off Atlantic City, New Jersey, by Fishermen's Energy and GL Garrad Hassan (Reference 42). Sea haze and humidity provide more aerosols for light reflection and a stronger signal-to-noise ratio, but they also increase the atmospheric extinction rate of the laser beam. We estimate that 10 to 15 km (rather than 25 km) is a more likely offshore wind mapping range for volume-scanned LIDAR.

Virginia has applied to BOEMRE for a Section 238 research lease, with nine sub-blocks for turbine testing located at a range of 11 to 14 km east-southeast (E-SE) of the CLT (Figure 13). Three to six wind turbines could be sited on these sub-blocks and would be within the likely accurate range of a volume-scanning LIDAR on the CLT, which would provide a unique capability to measure the performance of advanced offshore wind turbines.

Figure 13. Virginia's proposed Section 238 research lease. If volume-scanning LIDAR units on fixed platforms can be demonstrated to have an accurate radial velocity measurement range of 15 km, then the CLT could monitor incoming winds and wakes of test turbines located E-SE of the CLT, and two new platforms could completely map the Virginia commercial lease area.

A volume-scanning LIDAR unit on the CLT could be used to measure the incoming wind velocity immediately upwind of the test turbine rotors, across the entire span of the rotor swept area, which is critical to understanding the aerodynamic loads on the rotor and consequent bending moment on the rotor drive shaft. The same LIDAR unit can make similar wind velocity measurements downwind of the turbine rotors, such that the turbine wake and velocity deficit can be characterized at different downwind distances. Turbine wake velocity data are critical for determining the optimal spacing between turbines in a commercial project design, as well as the wake-induced turbulence that rotors and drive-trains must be designed to withstand. As shown in an aerial photo of the Horns Rev 1 wind project off Denmark (Figure 14), wake-induced turbulence can impact turbines at least five rows downwind of the leading upwind row.

Figure 14. Wake turbulence visualized by natural contrail formation at Horns Rev 1. Wind speeds here are higher, and the wakes correspondingly longer, as compared with the velocities shown in the volume-scanning LIDAR image of Figure 6. Source of photo: Reference 43.

Figure 15 illustrates the two types of instrumentation that could be used to meet the above objectives for test turbines on Virginia's Section 238 research lease. One alternative is to use two validated and traceable buoy-based vertical-profiling LIDARs, one located upwind of a test turbine, and one located downwind of a test turbine. Based on a recent quote from AXYS Technologies (Reference 44), the cost of a single WindSentinel buoy would be $1.35 million. This does not include ship time or personnel to deploy the buoy, which would bring the total cost to about $1.6 million per buoy. Given a single ship mobilization, two WindSentinel buoys probably can be purchased and installed at two initial monitoring sites in the Virginia Wind Energy Area (WEA) for a total cost of $3 million. An additional $500,000 should be budgeted for recovering these buoys after a monitoring period of just under 12 months (to avoid need for BOEMRE lease), temporarily mooring them adjacent to the CLT for revalidation, and then re-deploying them to two new monitoring sites in the Virginia WEA.
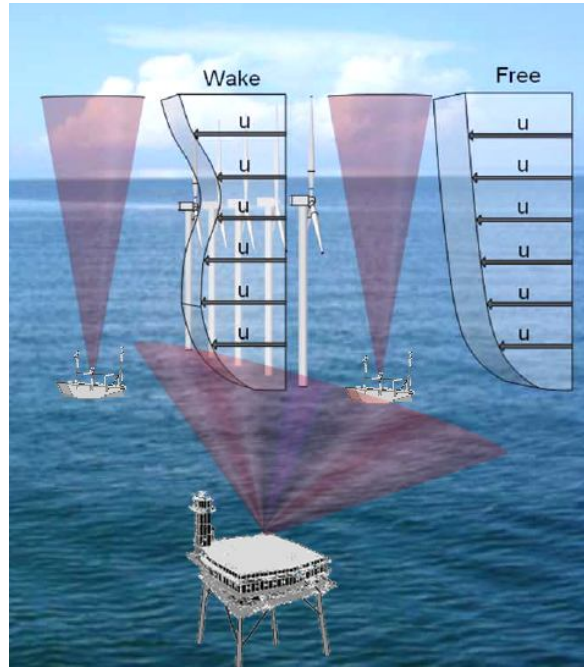
Figure 15. Conceptual illustration of LIDAR instrumentation alternatives for testing offshore wind performance and characterizing velocity-deficit in turbine wakes at NOWTC test pads, by using either a single volume-scanning LIDAR on the CLT or two buoy-based profiling LIDARs.

By comparison, a WindTracer volume-scanning LIDAR is estimated to cost $1.5 million (Reference 45). Installation on the CLT, including power supply, is estimated to cost an additional $500K. Thus, a fixed volume-scanning LIDAR would cost one-third less than two WindSentinel buoys and also have much greater capabilities. Such a volume-scanning LIDAR on the CLT could characterize the wakes of multiple test turbines at various downwind distances, whereas to perform the same wake characterization of multiple test turbines, the buoys would have to be continually relocated, at considerable cost for ship mobilization and crew time. Therefore, a volume-scanning LIDAR on the CLT that can demonstrate "bankable" wind speed accuracy at a range of 15 km would be much more cost-effective for monitoring test turbines on Virginia's proposed Section 238 lease sub-blocks east-southeast of the CLT (Figure 13).

As described later in this section, Phase III would involve installing two new-build metocean and environmental data acquisition platforms at the mid-points of the northern and southern borders of the Virginia commercial lease area, providing timely data to better inform commercial project site selection, estimates of annual energy production, lease valuation, and long-term monitoring of cumulative wake effects on the natural wind field as projects are commissioned.

In order to realize the above-described benefits, field trials are required in Phase II, to determine the accuracy of volume-scanning LIDAR technology by coastal testing of a volume-scanning LIDAR unit on the roof or upper story of an oceanfront hotel in Virginia Beach, to determine its accuracy over extended ranges of 15 to 25 km. Such testing could be carried out on a NASA-Langley prototype unit if funding from other sources can be secured for its adaptation as a ground sensor for offshore winds; otherwise a WindTracer could be purchased for this testing.

A proof-of-concept field trial of the NASA-Langley volume-scanning LIDAR is being funded by NASA's Earth Science Technology Office, and is scheduled to take place in October 2011, using a trailer-based system that will be positioned on the Cape Henry coast at Fort Story with thanks owed to the U.S. Navy for hosting this trial. This trial will measure line-of-sight wind speed and direction, and compare results with conventional anemometer mast measurements at the CLT, and at the First and Third Islands of the Chesapeake Bay Bridge Tunnel.

Assuming a successful proof-of-concept field trial in October 2011 and subsequent attraction of six to eight months of additional funding for sensor adaptation, then the design and assembly of a dedicated prototype offshore volume-scanning LIDAR unit could begin by July 2012. If this can be accomplished in nine months, then Phase II coastal validation could begin by April 2013. Assuming these tests indicate that from a protected coastal location, a volume-scanning LIDAR can yield accurate wind speed and direction to a range of 15 km, then the prototype unit would be ready to be moved offshore and established on the CLT for more rigorous ocean testing.

A leading candidate Phase II test site might be the Wyndham Hotel at 57th Street and Ocean Front Ave., which has an unobstructed line of sight to the CLT (range 24.6 km, bearing ~83°) and existing conventional anemometer masts on the first (range 14.6 km, bearing ~309°) and third islands (range 18.8 km, bearing ~334°) of the Chesapeake Bay Bridge Tunnel (Figure 15). This hotel is a 17-story structure (approximately 55 m roof height) surrounded by residential housing, which gives it unobstructed lines of sight to coastal anemometer masts at Little Creek Amphibious Base, Lynnhaven Fishing Pier, Cape Henry, Dam Neck, and Sandbridge, as well as two inland masts at Norfolk International Airport and Naval Air Station Oceana (Figure 16).

Estimating $1.5 to 2.5 million as the cost of the prototype LIDAR unit, and adding $500K for its installation and initial testing at the Wyndham Hotel, including monitoring, data analysis, and preparation of a final report, the total cost of Phase II is estimated to be in the range of $2 million to $3 million. This would qualify volume-scanning LIDAR for monitoring offshore test turbines from the CLT as well as for wind resource mapping of Virginia's commercial lease area from new data acquisition platforms to be built and installed for this purpose in Phase III.

By July 2013, there should be three months of data from the coastal field trials of the Phase II volume-scanning LIDAR unit, sufficient to determine the range to which it can provide accurate offshore wind measurements for both validation of turbine performance curves (power output vs. wind speed plots) at test turbines, and for commercial resource mapping. At this point, decisions must be made regarding the direction of Phase III, which can have one of four possible scenarios, as detailed in the next section, depending on the early results of Phase II and also depending on how much farther along buoy-based LIDAR profilers have progressed in their acceptance for yielding bankable wind resource data.
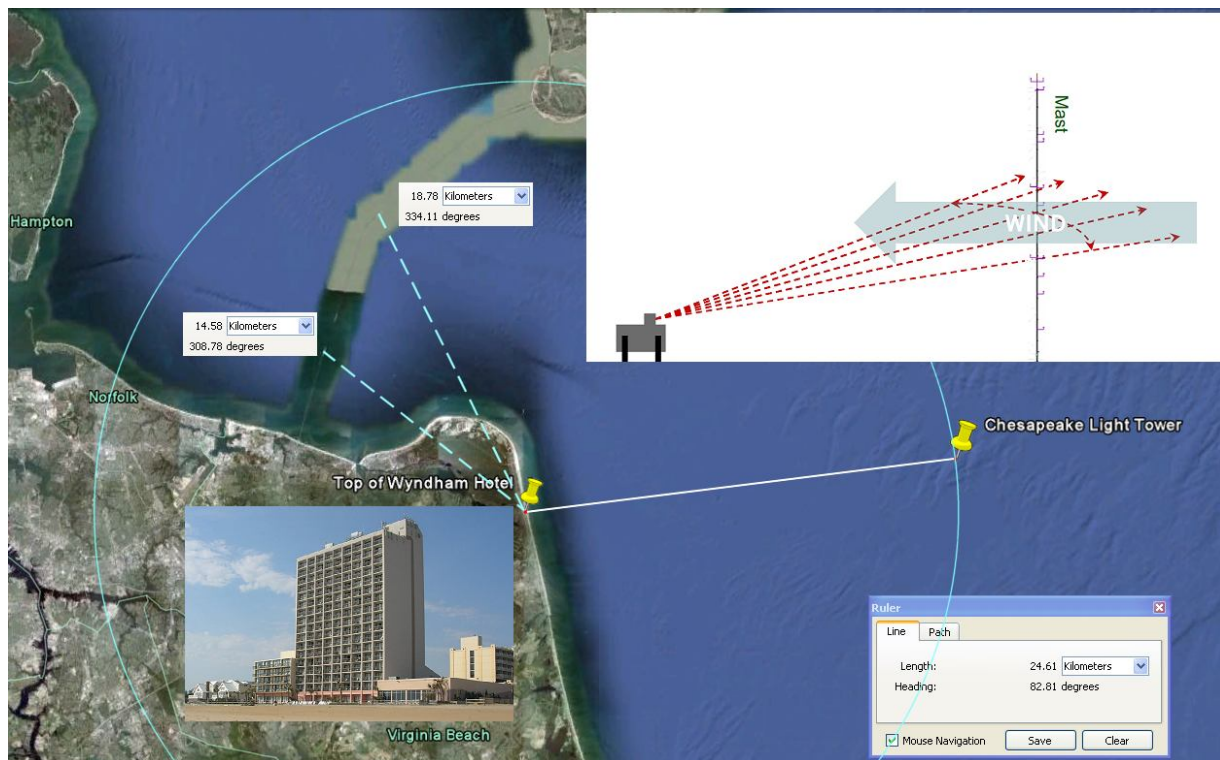
Figure 16. Ranges and bearings from the oceanfront Wyndham Hotel to the CLT and to the first and third islands of the Chesapeake Bay Bridge Tunnel.
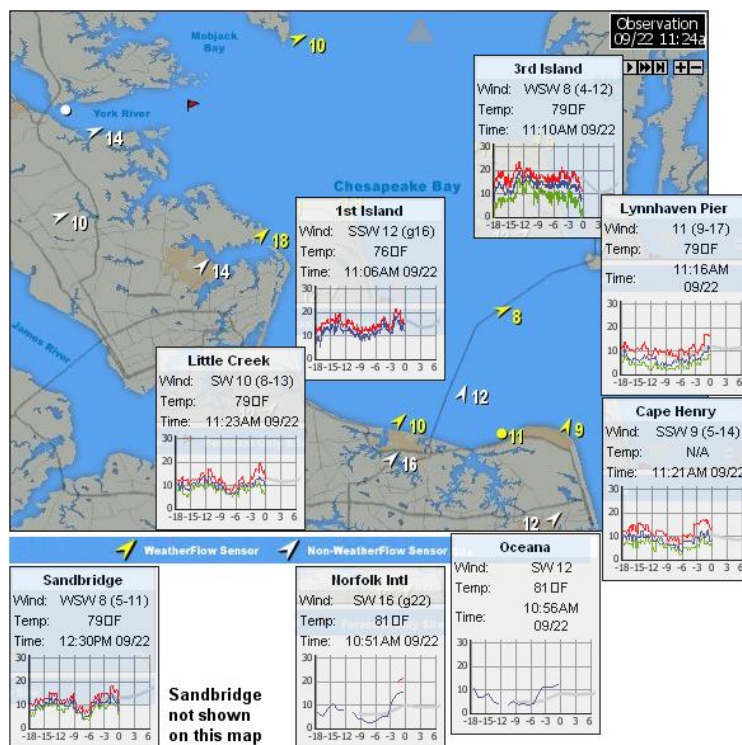

Figure 16. Nine offshore, coastal, and inland anemometer masts within volume-scanning LIDAR range of the Wyndham Hotel roof. In addition, James Madison University has installed a 50 m met mast on the coast at Dam Neck Combat Training Center in south Virginia Beach.

Phase III: Installation of Buoys or New Met Platforms in the Virginia Commercial Lease Area

Scenario A: Early results from Phase II and testing by others (e.g., off Atlantic City, New Jersey, as described in Reference 42) demonstrate that volume-scanning LIDARs *do yield* bankable wind data to a range of at least 15 km, *and* that buoy-based LIDARs *are accepted* for yielding bankable wind speed profiles when properly validated against a conventional meteorological mast or fixed vertical-profiling LIDAR.

Activities: Move volume-scanning LIDAR prototype out to the CLT and continue testing in a more remote, oceanic environment, by scanning towards shore and validating against measurements at coastal anemometer masts. Also begin monitoring turbine test sites in Virginia's Section 238 research lease.

Purchase two buoy-based vertical-profiling LIDAR units and validate in waters immediately adjacent to the CLT. Once validated, begin moving both buoys around the Virginia commercial lease area, occupying project sites for just under 12 months at a time to provide bankable offshore wind resource assessment at each site and scientific validation data for numerical metocean models.

Budget: $1 million to move the prototype volume-scanning LIDAR from its coastal validation location out to the CLT and continue validation in a remote, oceanic setting; this includes acquisition and installation of an offshore power supply for a volume-scanning LIDAR at the CLT.

In addition, $3 million for purchasing two buoys, installing these at a validation mooring adjacent to the CLT, and then deploying them to two sites within the commercial lease area, where they will monitor wind speed and direction at five to ten different elevations at each site for just under 12 months. Finally, a further $500K would be needed at the end of the first monitoring period to recover the buoys, revalidate them at the CLT, and then re-deploying to two new monitoring sites. The total budget for Phase III, Scenario A is $4.5 million.

Timetable: Order two LIDAR buoys in July 2012 and schedule validation at CLT to begin in March 2013. Occupy two initial monitoring sites in Virginia WEA by May 2013 and recover buoys in April 2014. Revalidate both buoys in May-June 2014 and re-deploy buoys to two new monitoring sites from July 2014 through June 2015.

Scenario B: Early results from Phase II and testing by others (e.g. off Atlantic City) demonstrate that volume-scanning LIDARs *do yield* bankable wind data to a range of at least 15 km, *but* that buoy-based LIDARs *are NOT accepted* for yielding bankable data.

Activities: Move the volume-scanning LIDAR prototype out to the CLT and continue testing in a more remote, oceanic environment. Also begin monitoring turbine test sites in Virginia's Section 238 research lease.

Begin site survey and characterization of met platform sites in Virginia's Section 238 research lease, located along the southern and northern edges of Virginia's commercial lease area (see map in Figure 13). Follow up with design, permitting, acquisition, and installation of two fixed platforms that will support additional volume-scanning LIDAR units for full-coverage mapping of the Virginia WEA.

Budget: $5 million for site surveys plus $10 million for design, permitting, fabrication, and installation of two new data acquisition platforms. Based on information compiled to date (Appendix C), it is estimated that a new platform with only LIDAR (without mast) can be sited, permitted, fabricated, and installed for $6 million.

If two identical platforms are produced to the same design specifications, then economies of quantity discounts on component order, serial production, and one-time mobilization and demobilization charges for installation equipment could reduce the cost per platform by up to 20%. Installation economies are more likely to be realized in summer than at other seasons, when both towers can be installed in a single weather window. The total budget for Phase III, Scenario B is $15 million.

Timetable: Characterize data acquisition platform sites with surveys conducted during the summer of 2012. Begin tower design and permitting activities in January 2013. Anticipate installation and commissioning 12 months later, such that data collection can begin by January 2014.

Scenario C: Early results from Phase II and testing by others (e.g. off Atlantic City) demonstrate that volume-scanning LIDARs *do NOT yield* bankable wind data, *but* that by mid-2012, buoy-based LIDARs *are accepted* for yielding bankable wind data.

Activities: Purchase two buoy-based vertical-profiling LIDAR units and validate in waters immediately adjacent to the CLT. Once validated, begin moving both buoys around the Virginia commercial lease area, occupying project sites for just under 12 months at a time to provide bankable offshore wind resource assessment at each site and scientific validation data for numerical metocean models.

Evaluate Phase II results to determine whether there is sufficient potential for improved accuracy to justify modification and continued coastal testing of prototype volume-scanning LIDAR unit. Estimate the cost of additional development work and investment required to improve its accuracy.

Budget: $3 million for purchasing two buoys, installing these at a validation mooring adjacent to the CLT, and then deploying them to two sites within the commercial lease area, where they will monitor wind speed and direction at five to ten different elevations at each site for just under 12 months. A further $500K would be needed at the end of the first monitoring period to recover the buoys, revalidate them at the CLT, and then re-deploy to two new monitoring sites.

Depending on the evaluation of Phase II results, either discontinue volume-scanning LIDAR testing or spend up to an additional $1 million for making improvements to the prototype unit and continuing coastal testing. Therefore, the total budget for Phase III, Scenario C could range from $3.5 million to $4.5 million.

Timetable: Order two LIDAR buoys in July 2012 and schedule validation at CLT to begin in March 2013. Occupy two initial monitoring sites in Virginia WEA by May 2013 and recover buoys in April 2014. Revalidate both buoys in May-June 2014 and re-deploy buoys to two new monitoring sites from July 2014 through June 2015.

Scenario D: Early results from Phase II and testing by others (e.g. off Atlantic City) demonstrate that <u>volume-scanning LIDARs</u> *do NOT yield* bankable wind data, *and* that <u>buoy-based LIDARs</u> *are NOT accepted* for yielding bankable wind data.

> <u>Activities</u>: Evaluate Phase II results to determine whether there is sufficient potential for improved accuracy to justify modification and continued coastal testing of prototype volume-scanning LIDAR unit. Estimate the cost of additional development work and investment required to improve its accuracy.

> <u>Budget</u>: Difficult to estimate, pending the results of Phase II and analysis of trial results. A maximum budget of $1 million would be consistent with Scenario C.

> <u>Timetable</u>: Hardware improvements and additional testing may require anywhere from 6 to 18 months, with 12 months being a mid-range estimate. This essentially is a continuation of Phase II, anticipating Scenarios A or B as a likely outcome, with a one-year delay of implementing Phase III under one of those scenarios.

Under Scenarios A and C, a year of bankable wind profile data would be available from LIDAR buoys at two monitoring sites by April 2014 and at two additional monitoring sites by July 2015. Under Scenario B, a year of bankable wind profile data would be available over the entire commercial lease area (not just two or four sites) by January 2015.

Scenarios A and C compare favorably to the prospects for a commercial developer being able to obtain wind data. If the Virginia Call is issued in October 2011, with a 45-day response period, and assuming there is substantial competitive interest, BOEMRE could initiate a competitive leasing process in early 2012. Assuming 9 months to develop, hold, and decide a lease auction, a developer could receive a commercial lease off Virginia by year-end 2012. Once the lease is executed, a developer must submit a Site Assessment Plan (SAP) within 6 months. Assuming the SAP is approved in 60 days, a developer then would need 8 more months to order, validate, and install a LIDAR buoy, such that on-site data acquisition could begin in May 2014.

Although Scenarios A and C provide the lowest-cost and most quickly available wind data, neither provides a fixed structure for monitoring the commercial lease area. Such a structure might be needed for avian monitoring with S-band or X-band marine radar, which have a reported range of only 11 km (References 46 and 47). Discussions with avian experts and regulatory agencies will be required to determine if avian monitoring should be directly within the commercial lease area or if CLT-based avian monitoring from tens of kilometers away will adequately address science needs and also meet environmental permitting requirements.

If the best available science indicates that avian activity is relatively homogeneous across this stretch of ocean area off Virginia, then avian data collected by marine radar on the CLT may be adequate for obtaining permits, particularly with the condition that additional marine radars would be installed in the actual project site for post-construction avian monitoring. Typically, such radars are installed on offshore substation platforms (for example, see Reference 48).

Another important consideration is that Scenarios A and C would provide wind profile data at only two buoy mooring sites per year, which may be of much less benefit than providing full three-dimensional coverage of the entire commercial lease area. Combined with the benefits of having a fixed platform for closer avian monitoring, Scenario B may be preferred in any case.

Appendix A – Vertical Profiling LIDAR Systems

	Pulsed Lidar	CW Lidar
Height resolution	Constant	Variable
Velocity resolution	Spectral broadening due to pulse	CW => no spectral broadening
Concurrent heights	Yes - ToF device	No - focussing device
Profile deconvolution	Square sensitivity function	Lorentzian sensitivity function
Points in conical scan	4 (Windcube)	50 (ZephIR)
Number of heights	10 (Windcube)	5 (+ cloud correction) (ZephIR)
Cloud correction	Not needed	Yes

Pulsed and CW (continuous wave) Lidars have different strengths and weaknesses, e.g.

 - the CW Lidar has greater redundancy associated with its conical scan and has no spectral broadening due to the degradation of frequency resolution by a finite pulse length, therefore exhibits better intrinsic velocity resolution.

 - the pulsed Lidar's simple sensitivity function, constant height resolution, greater number of height gates, and measurement at effectively concurrent heights should allow more accurate deconvolution of volume averages of arbitrary wind shear profiles.

Figure A-1. Technical features omparison between pulsed LIDAR profilers (e.g., WindCube, Galion, Vindicator) and continuous wave profilers (e.g. ZephIR).

Zephir – Natural Power Consultants

- Continuous Wave
- Variable focus setting
- VAD Scan 50 points, rotating wedge
- 60° elevation angle
- Cloud correction algorithm
- CE marked – eyesafe IEC 60825-1

- Measures to 200 m in good conditions
- Minimum range 10 m
- 5 heights sequentially
- 3 sec per height, 1 sec to change
- about 30 measurements at one height in 10 min
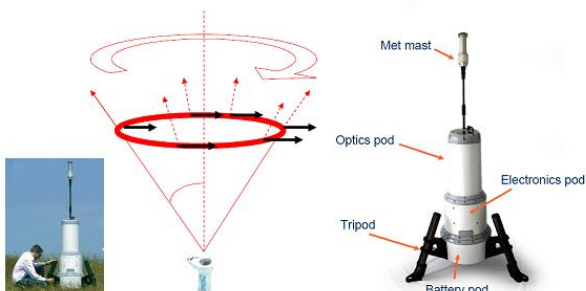- € 125.000

- 1.56 µm fiber laser
- 1 W output power
- 7 cm diameter lens
- No offset on LO
- RIN and not head or tail wind
- One LOS every 20 ms
- Frequency resolution 200 kHz

Figure A-2. ZephIR continuous wave LIDAR wind profiler.

WindCube – Léosphère

- Range gated
- Fixed focus at ~100 m
- 4 directions, 90° start-stop wedge
- 60° elevation angle
- eyesafe IEC 60825-1

- 1.54 µm
- 200 ns pulse
- 10 µJ
- 20 kHz
- 500 ms to get one LOS velocity
- 10000 averages per LOS
- 5 cm diameter lens
- Offset on LO
- Frequency resolution 5 MHz

- Measures to 200 m in good conditions
- Minimum range 40 m
- 10 heights in parallel
- 4 sec per full revolution
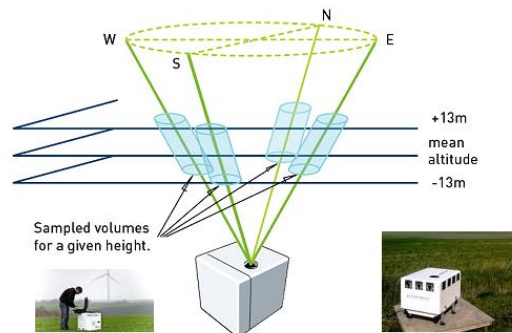- about 600 measurements in 10 min (125 completely uncorrelated)
- € 150.000

Figure A-3. WindCube pulsed LIDAR wind profiler.

Galion – Sgurr Energy

- Range gated
- Collimated
- two axis scanner head
- eyesafe IEC 60825-1
- 9 month warranty

- 1.54 µm
- 180 ns pulse
- 10 µJ
- 20 kHz
- 50 mm aperture
- Offset on LO

- Measures to 200 m in good conditions
- 20 sec per full revolution
- 30 uncorrelated meas in 10 min (in 4 direction mode)
- + 30 vertical meas
- € 150.000

Figure A-4. Galion pulsed LIDAR wind profiler.

LASER ANEMOMETER SPECIFICATIONS

GENERAL SPECIFICATIONS

OPERATING TEMPERATURE	-40°C to 55°C
SYSTEM POWER REQUIREMENTS	110 VAC at 250 Watts Max.; 0°C - 55°C 110 VAC at 450 Watts Max.; -40°C - 0°C
OPERATION	Unattended, 24/7
REMOTE SUPPORT	Remote Access for Maintenance and Configuration
DATA OUTPUT FORMAT	Customer defined

FUNCTIONAL SPECIFICATIONS

OPERATIONAL WAVELENGTH	1550 nm
WIND SPEED RANGE	0-90 m/s
SENSING RANGE	30 to 150 meters
NUMBER OF SIMULTANEOUS REPORTING HEIGHTS	5 - User Configurable
DATA AVAILABILITY	1 Hz motion corrected wind speed & direction
DATA VALIDITY	Better than 90%
RANGE GATE PROBE DEPTH	± 20 meters
WIND SPEED ACCURACY	0.1 m/s @ 1 Hz data rate
VECTOR ORIENTATION	360° (± 180 degrees)
RELATIVE ANGULAR ACCURACY	±0.5° @ 8 m/s speed, 1 Hz
EYE-SAFETY	Class 1 Eye-Safe

Figure A-5. Vindicator pulsed LIDAR specifications for the AXYS WindSentinel buoy. Note from Figures A-3 and A-4 that the WindCube and Galion pulsed LIDAR units scan four different azimuths at a given tilt angle, with a complete scanner revolution requiring 4 seconds for the WindCube and 20 seconds for the Galion. This makes it difficult for these units to obtain accurate turbulence measurements. By comparison, the Vindicator uses three simultaneous beams, which makes turbulence measurements possible.
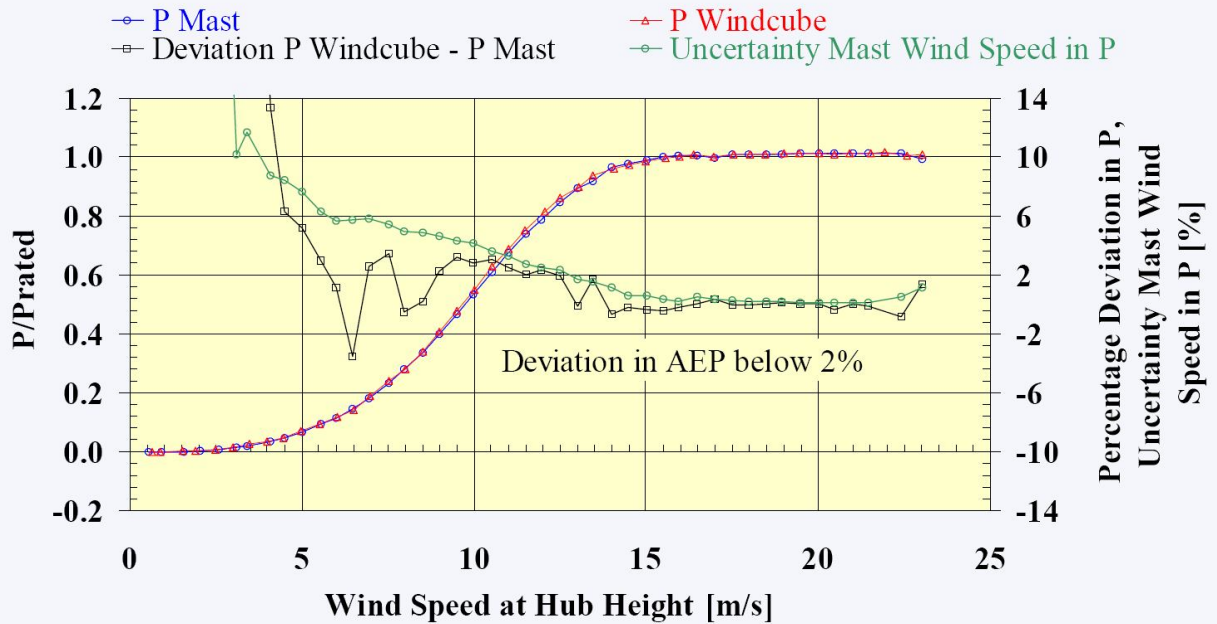
Figure A-5. Comparison of wind turbine power curves measured by a conventional mast with cup anemometers and a WindCube vertical-profiling LIDAR. Note that for all wind speeds of 4.5 m/s or greater, the deviation between the WindCube and cup anemometer power curves is less than the inherent uncertainty in the cup anemometer power curve (Source: Reference 22).
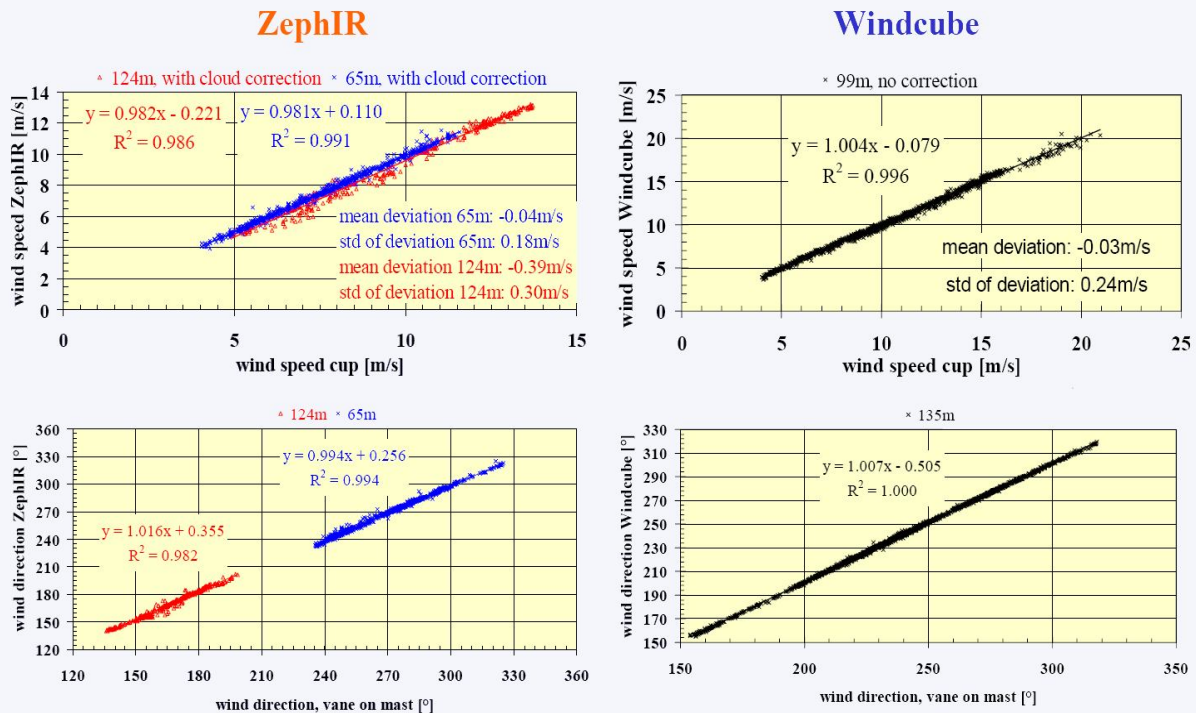

Figure A-6. Comparison of mast measurement correlations between ZephIR continuous-wave LIDAR and WindCube pulsed LIDAR for wind speed and direction (Source: Reference 22).
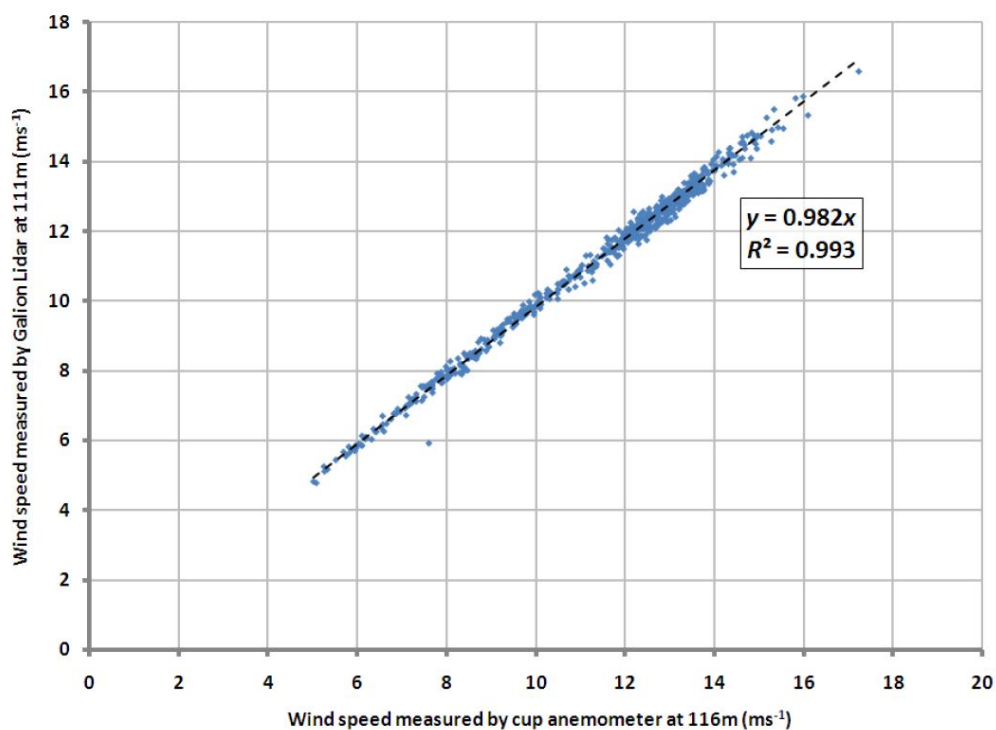
*Figure A-7. Mast wind speed measurement correlations for Galion pulsed LIDAR
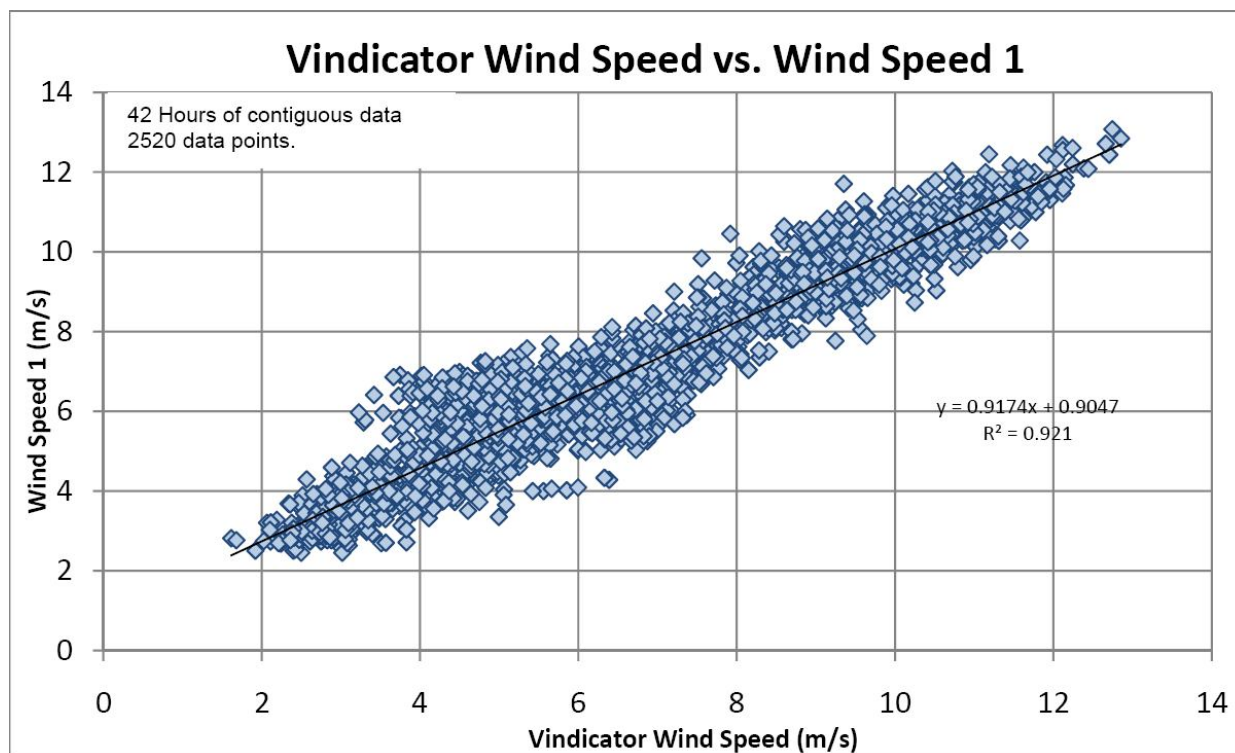(Source: Reference 23).*

*Figure A-8. Mast wind speed measurement correlations for Vindicator pulsed LIDAR.
(Source: Reference 27).*
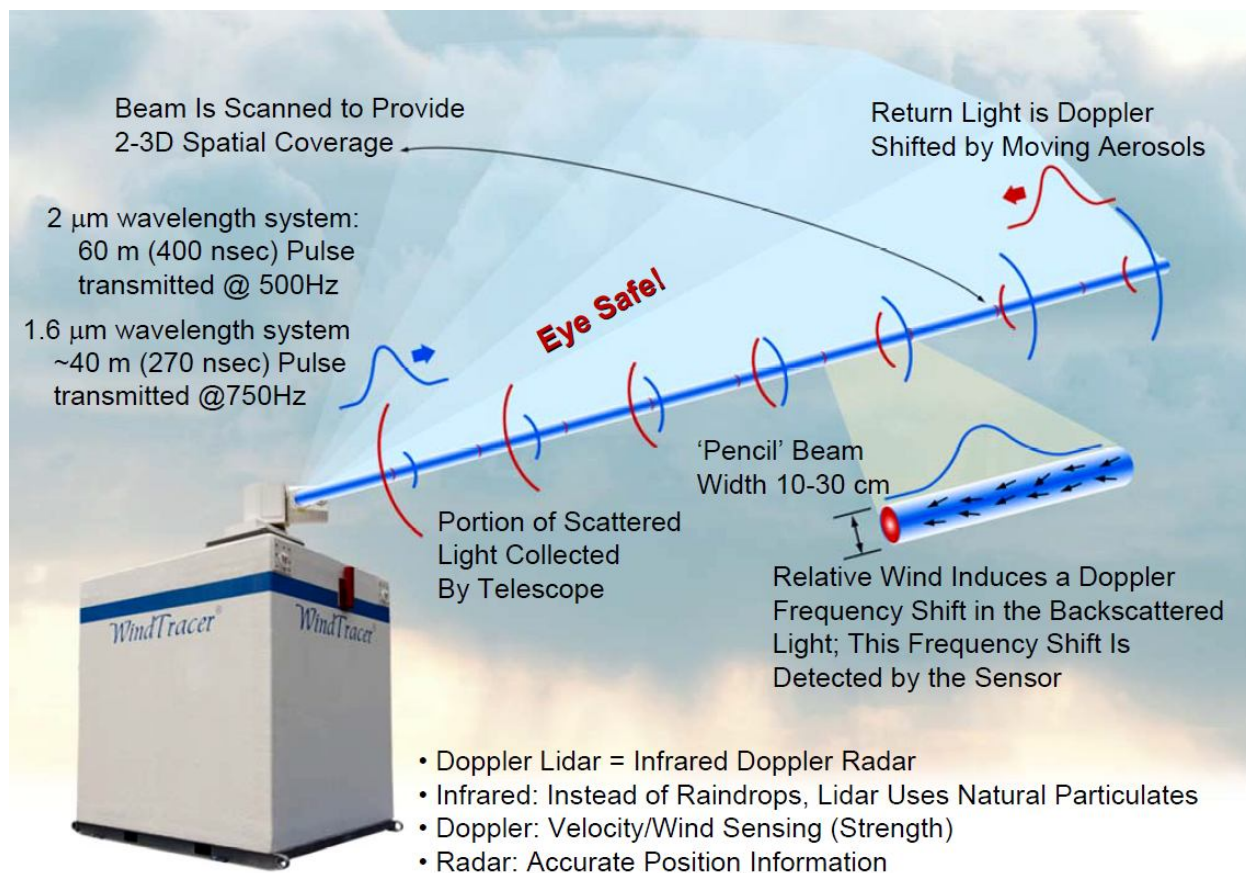
Appendix B – Volume-Scanning LIDAR Systems

Beam Is Scanned to Provide
2-3D Spatial Coverage

Return Light is Doppler
Shifted by Moving Aerosols

2 μm wavelength system:
60 m (400 nsec) Pulse
transmitted @ 500Hz

1.6 μm wavelength system
~40 m (270 nsec) Pulse
transmitted @750Hz

Eye Safe!

'Pencil' Beam
Width 10-30 cm

Portion of Scattered
Light Collected
By Telescope

Relative Wind Induces a Doppler
Frequency Shift in the Backscattered
Light; This Frequency Shift Is
Detected by the Sensor

- Doppler Lidar = Infrared Doppler Radar
- Infrared: Instead of Raindrops, Lidar Uses Natural Particulates
- Doppler: Velocity/Wind Sensing (Strength)
- Radar: Accurate Position Information

Figure B-1. WindTracer volume-scanning LIDAR measurement principal.

- **Collect radial velocity data over a large spatial region**
- **Scan in azimuth at a constant elevation angle --- a tilt**
- **Apply VAD algorithm to the annular sector and derive vector velocity estimate for center of sector**
- **Repeat for next over-lapping sector**
- **Derive vertical profile from multiple tilts & ranges**
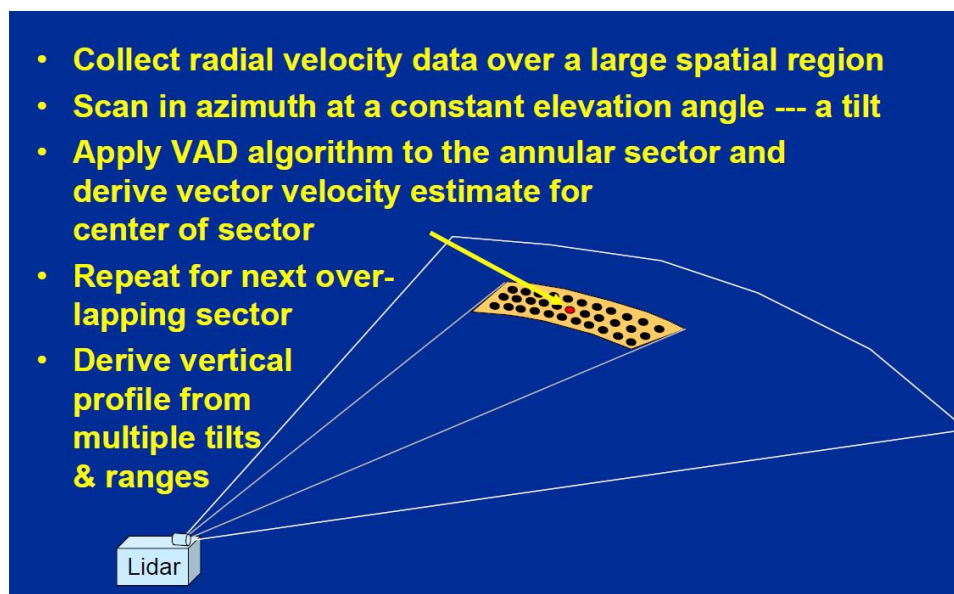
Lidar

Figure B-2. WindTracer method to estimate wind speed at mid-point of scanned annular sector.

Parameter	2 µm System Configuration	1.6 µm System Configuration
Transmit Wavelength	2022 nm	1617 nm
Average Power	1 W	2 W
Pulse Energy	2 mJ	2-5 mJ
Pulse Repetition Frequency	500 Hz	200-1000 Hz
Pulse Duration	400 ns (60 m)	~270 ns (40 m)
Aperture Diameter	>10 cm	>10 cm
Maximum Wind Speed	0 - 22 m/s, 0-40 m/s option	0 - 38 m/s standard
Maximum Range	8-10 km	8-12+ km
Velocity Accuracy	0.1 to 0.5 m/s	0.1 to 0.5 m/s
Output Grid Spacing	100 m typical, 10 m vertical	100 m typical, 10 m vertical

Figure B-3. WindTracer measurement specifications. Source: Reference 32.

**2 microns, 250 mJ, 5 Hz, 15 cm telescope
Transceiver: 6 x 12 x 27 inches, 75 lbs** | **2 microns, 2 mJ, 500 Hz, 10 cm telescope
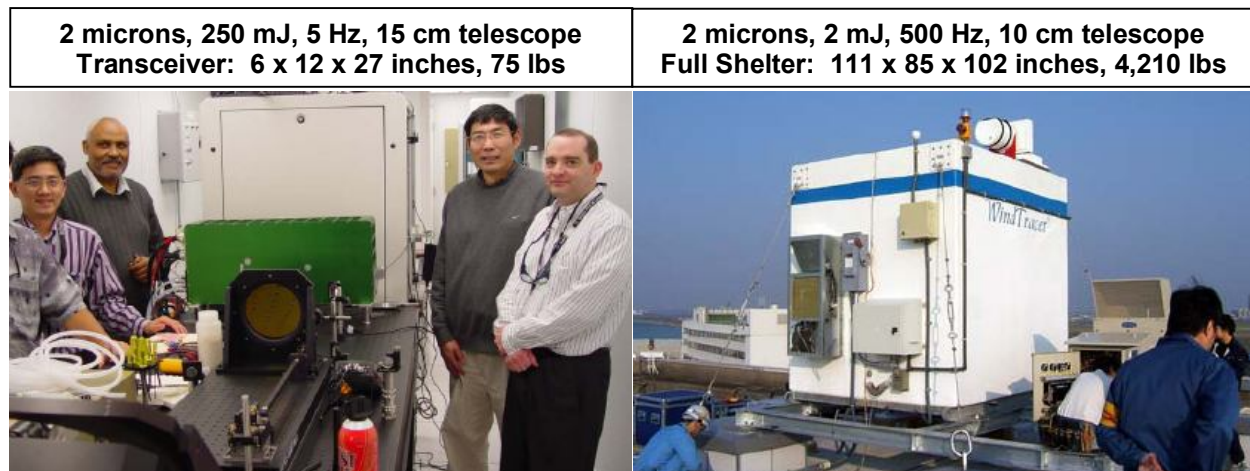Full Shelter: 111 x 85 x 102 inches, 4,210 lbs**

Figure B-4. Comparison of weight and dimensions for NASA-Langley (left) volume-scanning LIDAR with those of WindTracer (right). Source: Reference 34.

Appendix C – Offshore Met Mast and Platform Cost Estimates

This appendix summarizes publicly available information on the following offshore meteorological masts and data acquisition platforms:

- **FINO-1** meteorological mast, 110 m AMSL, which was installed 45 km north of Borkum Island in the German sector of the North Sea in July 2003. The fabrication and installation contract awarded to F+Z GmbH (marine subsidiary of Bilfinger Berger AG) was valued at €5.3 million ($6 million USD mid-2002; would likely cost $10 million USD mid-2011).

- **Nai-Kun** vertical profiling LIDAR platform, which was installed in Hecate Strait east of the Queen Charlotte Islands off the Pacific coast of British Columbia in September 2007. The total acquisition cost was $2.5 CAN, and the same structure if fabricated mid-2011 is estimated to cost $3 million USD.

- **Humber Gateway** meteorological mast, 90 m AMSL, which was installed off the west coast of England in July-August 2009. The £2.4 million GBP design, fabrication, and installation contract was awarded to Seawind Marine, Ltd., during the fourth quarter of 2008, during which the exchange rate decreased from $1.78 to 1.46 USD per GBP, with a corresponding USD contract value of $3.5 to 4.3 million.

- **NAREC** offshore demonstration monitoring platform to be installed during the fall of 2011 offshore Blyth in the UK. This platform will include a conventional anemometer mast and a vertical-profiling LIDAR, together with wave and tidal monitoring instruments, bird and bat monitoring equipment, passive acoustic sensors to detect marine mammals, and vessel tracking based on Automatic Identification System (AIS) signals. The NAREC platform also will have a 360° observation platform and enclosed refuge shelter for personnel. McNulty Offshore Construction, Ltd. is carrying out pre-construction services and the expected construction contract is estimated to be £4-6 million GBP. At $1.55 USD per GBP the U.S. cost of this platform would range from $6.2 million to $9.3 million. As described by NAREC press releases at the end of this appendix, the substructure for this platform is three times more massive than that for the Humber Gateway met mast.

Project Data

Main Quantities of Structural Steel:
Jacket: 310 t
Platform Deck: 200 t
Heli Deck: 30 t
Measuring Mast: 30 t
Foundation Piles: 160 t

Levels:
Foundation Piles (Pile Tip): 58.0 m
Sea Bottom: 28.0 m
Reference level C.D.: ± 0.0 m
Platform Deck: + 20.0 m
Helicopter Deck: + 25.0 m
Top of Measuring Mast: + 101 m

Main Dimensions:
Jacket (Base): 26 x 26 m
Jacket (Top): 7.5 x 7.5 m
Platform Deck: 16 x 16 m
Heli Deck: 14 x 14 m

Location:
Borkum Riff
N 54° 01'
E 06° 35'
45 km North of Island Borkum
Water Depth: approx. 28 m

Installation time offshore: 06/2003

Figure C-1. FINO-1 offshore meteorological mast specifications and installation equipment.

www.naikun.ca/news_media/news.php?id=76

NaiKun Wind Meteorological Station Project Recognized With Prestigious Engineering Award

Vancouver, British Columbia – March 16, 2009 – NaiKun Wind Energy Group Inc. ("NaiKun Wind") announced today that the meteorological station at its project site in Hecate Strait has been recognized with an award from the Consulting Engineers of British Columbia.

The Award for Engineering Excellence was presented to Sandwell Engineering Inc. ("Sandwell") of Vancouver, British Columbia, the consulting engineers for the meteorological station project. A total of five awards were issued in different categories, with the award for the meteorological station issued in the Natural Resource, Energy and Industry category.

The meteorological station was sited, permitted, designed, fabricated, installed and commissioned in just six months. Local contractors were used to manufacture and install the structure, and there was no adverse impact on the environment or local fisheries. The station uses laser-based ZephIR LiDAR technology to measure wind speed, direction and other attributes at multiple heights.

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www.naikun.ca/news_media/news.php?id=44

NaiKun Installs Meteorological Station at Offshore Site

Vancouver, British Columbia – Sep 25, 2007 – NaiKun Wind Energy Group Inc., ("NaiKun") announced today it has installed a $2.5 million world-class marine meteorological station at its project site off the coast of Haida Gwaii (the Queen Charlotte Islands) in north western British Columbia under permit from the Haida Power Authority.

The recently installed marine meteorological station is equipped with several high-tech instruments that will measure and collect data pertaining to atmospheric conditions, wave and current climate, wind speed and direction and air and sea temperatures. The measurement data will also play an important role in pre-engineering the project and identifying the optimal siting of the wind turbine locations. This is the first offshore measurement station of its kind on the west coast of North America.

"The installation of the marine meteorological station is a critical step forward for the NaiKun project. The station is equipped with the most sophisticated measurement instruments available and will assist the company in pre-engineering and construction planning," noted Ray Castelli, President and CEO of NaiKun Wind Development. "In addition to the wind measurement system, the station is fitted with an acoustic doppler current profiler (ADCP) to measure current velocities and wave heights, periods and directions. This is one of the most advanced meteorological stations available and much of the design, componentry and assembly was done here in BC with local companies."

"The fact that a number of BC companies played important roles in the development and installation of this met station is significant. This kind of experience will help to improve the skills necessary to sustain growth in the wind industry," concluded Castelli.

Sandwell Engineering of Vancouver assisted NaiKun with the design of the meteorological station structure and co-ordination of installation. Fabrication was handled by Ramsay Machine Works Ltd in Sidney and Fraser River Pile and Dredge managed the transportation and installation of the structure. Closer to the project site in Prince Rupert, Broadwater Industries fabricated the drill platform and Foundex Explorations carried out bore hole extractions for soil sampling that will be used during the detailed design of the wind farm. Smit Marine provided the necessary tugboat services.

Design and Construction

This unique structure was designed to be strong enough to resist the extreme wave climate in the Hecate Strait with maximum wave height of 20 m. It is the first structure of its kind in BC and was fabricated and installed entirely using local resources.

PLATFORM
T.O. GRATING
EL. +26.232m

HHW
EL. +7.0m

LLW
EL. 0.0m

SEABED
EL. −9.5m

#914x19mm THICK
GRADE API 5L/X42
MIN. PENETRATION 30 m)

The pin piles are driven through the steel jackets and subsequently grouted in position. The seabed is expected to be scoured away from under the feet of the tripod.
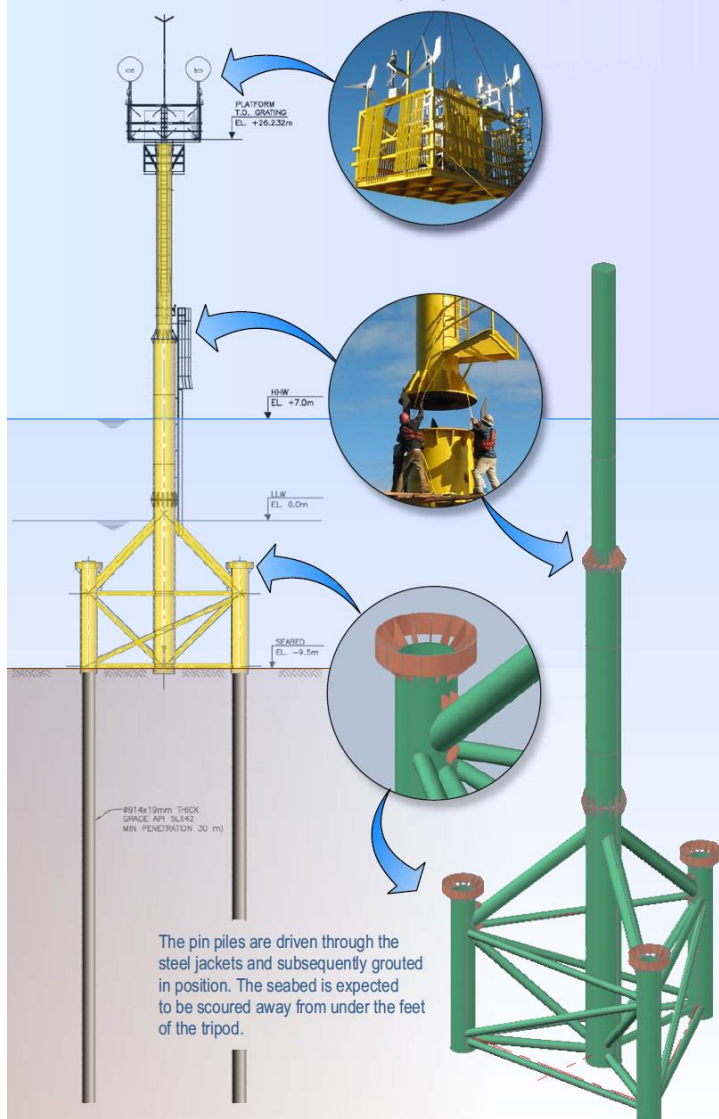
Figure C-2. NaiKun meteorological platform with vertical-profiling LIDAR.

£2.4 Million Humber Gateway meteorological mast EPC contract for Eon.

Client
Eon

Consulting Engineers
Scott Wilson

Project

In Q4 of 2008 Seawind Marine was awarded a £2.4M contract to design, construct and install a meteorological mast in the Humber Gateway for Eon. This met mast will then be used to monitor the met ocean and weather conditions in preparation for an offshore wind farm due for construction in 2013.

Method

Seawind worked closely with Scott Wilson Consulting Engineers to design and construct under a fast track programme a 90m met mast. These works included procuring and managing the fast track manufacture of a 101 Tonne monopile from a European supplier, fabricating a bespoke demountable access and platform system and installing all of the equipment during the summer of 2009 using the Lynn spud raising barge, a 400T crawler crane and 60T IHC Hydrohammer.

The monopile, platform, access systems, mast and ancillary equipment were all installed within 40 hours of on location working time. This ability to rapidly erect the equipment was due to the modular design that Seawind developed and enabled the project to be constructed in short weather window periods.

Seawind completed the work within budget, without incident and on programme despite some of the worst July and August weather conditions experienced in recent history.

Ref: W05

Figure C-3. Humber Gateway offshore meteorological mast.

Notice of the appointment of McNulty Offshore Construction Limited to carry out pre-construction services for offshore wind demonstrator monitoring platform

By Sheena McGeorge | 09/12/10 | In www.narec.co.uk/media/news

Following the conclusion of a public procurement exercise, Narec has appointed McNulty Offshore Construction Limited to carry out the pre-construction services for the offshore demonstrator monitoring platform works, with an expected construction value of between £4-6.

The monitoring platform represents the first phase of construction of Narec's **offshore wind** demonstration facility, which when completed will provide global turbine manufacturers with the opportunity to demonstrate their prototype **wind** turbine generators and foundations in the North Sea.

The platform will collect the necessary environmental data to inform the development, construction and operation of the demonstration site. The data gathering equipment likely to be located on the offshore platform shall have the ability, but not be limited to the collection of the following data:

- **Wind assessment** (wind speed and direction) - the data will be collected from a fixed met mast at up to five different elevations between 20 and 100 metres above platform level. In addition, the met mast will be fitted with LiDAR anemometry equipment to collect data across the swept area of a 150m diameter wind turbine rotor.

- **Bird monitoring** – using bird detection equipment to monitor the movement of birds (range, bearing, elevation and speed) at a range of up to 10 km. In addition, the device(s) should be able to determine the type of birds detected. Bird detection equipment shall provide a horizontal 360 degree field of view.

- **Vessel movement** - to record vessel movements up to a range of 10km. The system will be used in conjunction with the shipping Automatic Identification System (AIS).

- **Bat detection** - using a bat detection and recording device.

- **Subsea mammal detection** - to record subsea mammal types up to a range of 2km, giving the bearing and an estimate of range of any contact with a horizontal 360 degree detection arc.

- **Wave** data (both remotely and on the structure) - using on and off installation sensors to provide wave data.

- **Tidal data** - using a 'trawler proof' installation sensor.

- **Scour data** - long term monitoring of scour.

- **Weather station** - to provide air temperature, relative humidity, barometric pressure, solar radiation, rainfall and visibility (fog) data.

- **CCTV** - as required for providing visual observations.

- **General observations** - the offshore installation will provide a clear 360 degree view for personnel who may be placed on board. An enclosed refuge is required in case personnel are unable to leave the installation for any reason.

McNulty Offshore Construction Ltd will work with NAREC to confirm the requirements of the monitoring platform and develop the design, with the intention of the platform being constructed and in place by summer 2011.

McNulty Offshore require supply chain proposals for Narec's offshore demonstrator platform

By Sheena McGeorge | 07/07/11 | In www.narec.co.uk/media/news

McNulty offshore are seeking innovative proposals from the supply chain to install the Narec offshore demonstrator platform off Blyth. The structure comprises 398te drilled tripod foundation and transition piece, 45te platform deck, 23te met mast to 108m AMSL and ancillary environmental monitoring equipment.

Suppliers must be able to install over an autumn/winter 2011 window. This could be completed by separate lifts/contracts over a flexible installation window. Interested parties should contact brian.holland@mcnultyoffshore.com

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